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Alexander Graham Bell's optical disc recordings and other inventions

Dan Hutt

The latter part of the 19th century is known to historians as the Gilded Age of Invention. The flurry of inventions created by Alexander Graham Bell is characteristic of the period, when a handful of seemingly heroic individuals laid the groundwork for 20th century technology. While the technological and economic conditions were right for commercialization of the telephone, many of Bell's other ideas such as the optical disc recording faded into obscurity. Unlike his contemporary Thomas Edison, who strictly invented to exploit perceived market demand, Bell's activities were driven by the sometimes random forces of his curiosity. We discuss many of the creations of Nova Scotia's most illustrious resident inventor.

La fin du XIX^{e} siècle est considérée par les historiens comme l'âge d'or des inventions. La multitude d'inventions d'Alexander Graham Bell est caractéristique de cette époque où une poignée de valeureux chercheurs ont pavé la voie à la technologie du XX^{e} siècle. À une époque où la technologie et la situation économique étaient propices à la commercialisation du téléphone, bon nombre d'autres idées de Bell, comme l'enregistrement sur disque optique, ont été reléguées dans l'ombre. Contrairement à son homologue de l'époque, Thomas Edison, dont les inventions répondaient aux seuls besoins pressentis du marché, Bell était surtout animé par une curiosité sans bornes. Un grand nombre des inventions du plus illustre résident de la Nouvelle-Écosse seront abordées ici.

After the telephone

In July 1877, Alexander Graham Bell married Mabel Hubbard and the newlyweds set off on an eighteen month honeymoon in England. Bell's famous telephone patent, number 174,465, had been granted just the year before and he was already making money from the fledgling Bell Telephone Company. In Europe, Bell enjoyed celebrity status, invited to speak at learned societies and meeting Queen Victoria and other heads of state and dignitaries. But even on his honeymoon, Bell was already thinking about ways to improve the telephone. He recognized that a weakness of the telephone described in the patent was its magneto-inductive transmitter, which was not powerful enough for long distance communication. A practical variable resistance transmitter would have to be developed which could modulate the large currents necessary for long distance telephony.

Bell was also aware that powerful adversaries had taken notice of the telephone and were hard at work, trying to circumvent his patent (Carlson, 1994). The giant Western Union Telegraph Co. had hired the famous inventor Thomas Edison to out-do Bell and any other claimants to the telephone idea (Bruce, 1973). Even before the Bells' returned from their honeymoon, Edison had applied for a patent for the variable resistance carbon button transmitter in February, 1878.

Optical communication and photoacoustics

Upon his return, Bell immediately set to work to out-invent Edison and come up with his own improved transmitter. Although Bell never did make a useful transmitter (the Bell Telephone Company bought a transmitter patent from Emile Berliner in1878), along the way he was introduced to the element selenium, a material whose resistance depends on the amount of light falling upon it. Bell used the photoresistive property of selenium as the basis for an optical communication system that could transmit a voice message hundreds of meters on a beam of light. Although the "photophone" as Bell called it, faded into obscurity, Bell still goes down in history as being the first to demonstrate wireless voice communication (Fig. 1) (Hutt et. al., 1993).

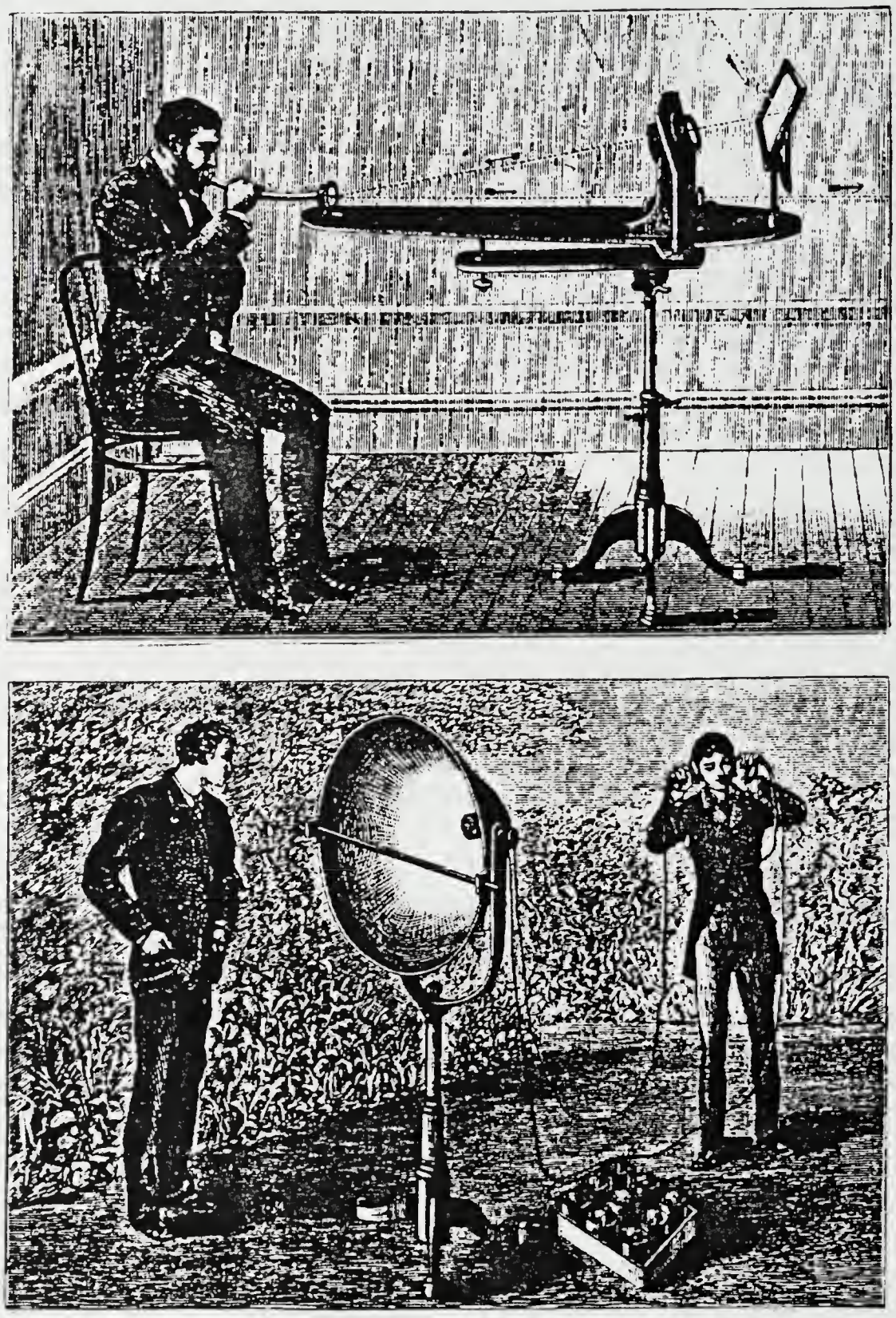


Fig 1 Optical communication in 1880: Bell's photophone. The left panel shows Bell sitting at the transmitter which projects a beam of modulated sunlight to the receiver shown on the right. (Courtesy of Heritage Canada Alexander Graham Bell National Historic Site)

While working on the photophone, Bell noticed that pulses of intense sunlight focussed on the surface of an object, caused many materials to emit pulses of sound. The intensity of the sound depended on the intensity of the light, and on the type and dimensions of the material. This photoacoustical effect is due primarily to the coupling of heat from the surface of the object that has absorbed some of the radiation to the air near the object's surface. The slight pressure change associated with local heating of the air is a sound wave. Bell created light pulses by chopping a beam of sunlight with a rotating, slotted wheel. With pulse frequencies in the hundreds of hertz, an audible tone could be heard emanating from the object.

While studying the photoacoustical properties of many, sometimes amusing things (Fig. 2), Bell theorized about the propagation of heat pulses into materials. He thus became the first person to describe the basic idea for the technique known today as "thermal wave imaging" (Thomas et. al., 1993). In this nondestructive testing technique, a modulated source of infrared light irradiates the surface of an object causing a wave of heat energy to propagate into it. The thermal wave is reflected and scattered by subsurface defects and when some of the thermal wave is reflected back to the surface, a temperature distribution is created that can be visualized with an infrared camera. Analysis of the infrared image of the objects surface yields information about its underlying structure.

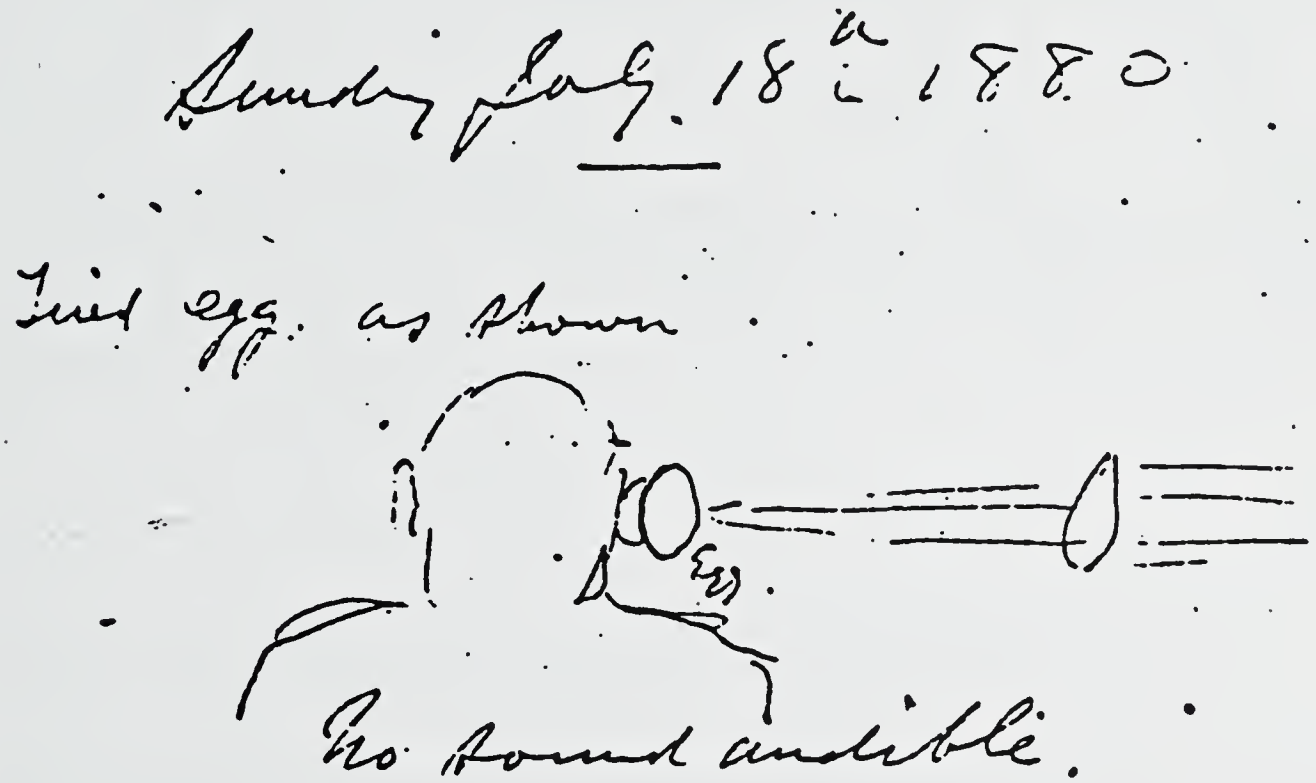


Fig 2 Sketch from Bell's notebook dated July 18, 1880 showing photoacoustical analysis of an egg. Result: "no sound audible".(A. G. Bell Lab Notes, Vol. 2 p. 63 (1880))

Later, Bell studied how the intensity of the sound emitted by objects depended on the wavelength of the light used to stimulate them. He discovered that some materials respond more to the red and infrared part of the spectrum while others did not have a notable spectral dependence. Bell proposed that the wavelength dependence of the sound be used to classify materials. Then Bell and his assistant, Sumner Tainter, built a device which they called the "spectrophone" but which was really the world's first photoacoustic spectrometer (Fig. 3). Bell is now recognized as the father of the very important field of photoacoustic spectrometry (Rosenwaig, 1980). Today, you may encounter photoacoustics when you have your car inspected; it is the technique used to analyze the exhaust of a car engine.

The induction balance

On July 2, 1881, the newly elected president of the United States, James Garfield was shot and wounded by a would-be assassin. It was widely publicized that the bullet in Garfield's body could not be located and that the president's life was in danger. Bell immediately set to work adapting an "induction balance" which he had experimented

with while studying inductive interference on telephone lines. The induction balance consisted of two flat coils of wire, one connected to a battery via an electro-mechanical interrupter (i.e. "buzzer") and the other connected to a telephone receiver. The intermittent current flowing through the first coil could induce an audible tone in the telephone receiver via the second coil. The coils could be carefully positioned or "balanced" so that their mutually induced currents cancelled out and the telephone receiver was silent. A conducting material brought into the vicinity of the balanced coils would perturb the balance and thus be detected by causing a tone to be heard in the telephone (Bell, 1882).

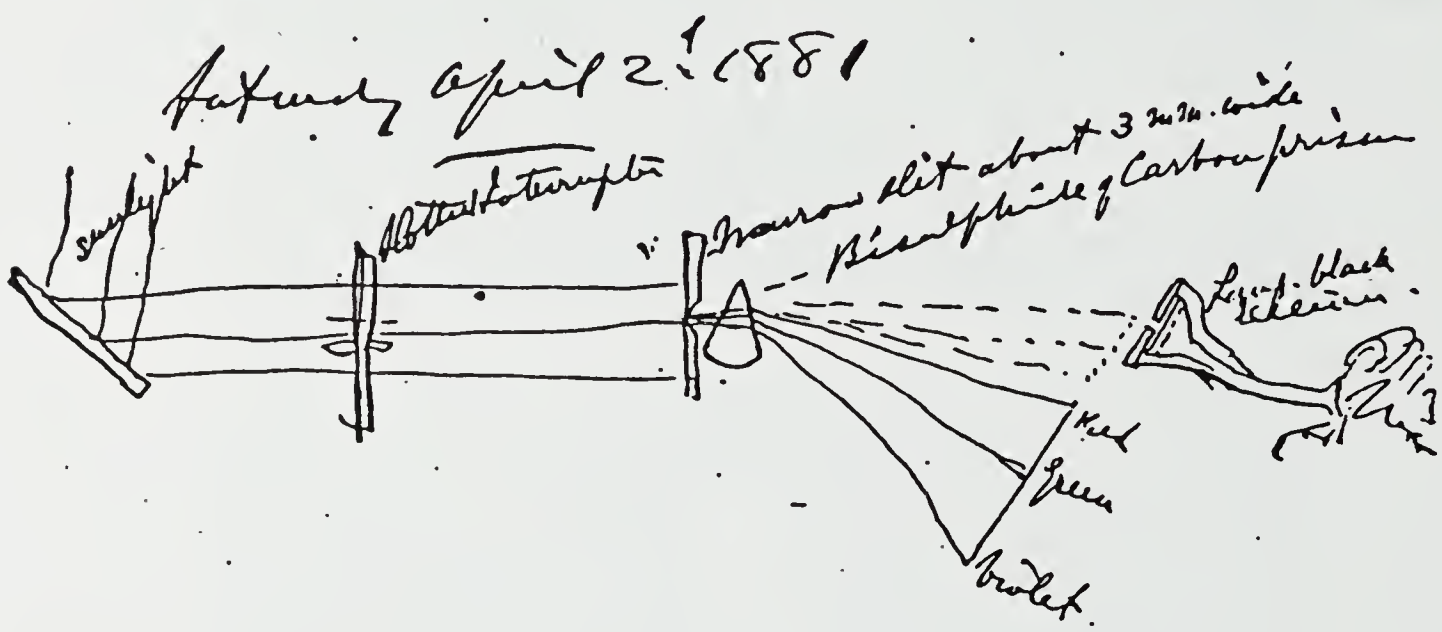


Fig 3 Sketch from Bell's notes dated April 2, 1881 showing the spectrophone concept: the world's first photoacoustical spectrometer. (A. G. Bell Lab Notes, Vol. 4 p. 17 (1881))

In their Washington laboratory, Bell and Tainter worked furiously throughout the summer of 1881 as the president's condition deteriorated. They experimented with bullets in their mouths and in their armpits, trying to increase the sensitivity of the induction balance. Finally, they tested the apparatus on the president in late July with negative results. On August 1 they tried again, this time getting a faint response from the lower abdomen, where doctors had suspected the bullet to be. Garfield died soon after. An autopsy showed that the bullet was located too deep within his body to have been detected by the induction balance. It also showed that the bullet was safely encysted; what probably killed Garfield was not the bullet but infection caused by the probing fingers of his physicians.

Bell and Tainter doggedly continued improving the induction balance until in October they successfully demonstrated it on Civil War veterans who still bore bullets in their bodies. Bell never patented the induction bullet probe, not wanting to profit from a life-saving device but it was used commercially by others until the discovery of x-rays in 1896 (Kuhfeld, 1991).

Another induction balance tangent was the "audiometer". By displacing the two coils of an induction balance a given distance along a scale, an audible tone of well defined intensity was produced in the telephone receiver. Bell used the device to test the hearing of hundreds of school children. He discovered residual hearing in many children thought to be completely deaf. Any capability to hear, no matter how slight, could be exploited to teach the child to speak. He also discovered that among pupils in public schools, a large percentage suffered some degree of hearing impairment and

some, who were considered dull-witted, were actually unable to hear their teacher properly (Bruce, 1973). In recognition of this work, the scale of relative sound intensity, the bel was named after him (Pierce, 1981). Today the decibel, which is one tenth of a bel, is well known.

The Michelson-Morley experiment

In 1880 Bell was awarded the Volta prize by the French government in recognition of the invention of the telephone. With the 50,000 francs he received with the prize, Bell founded the Volta Laboratory in Washington DC with his long-time associate Sumner Tainter and Bell's cousin Chichester Bell who had trained in England as a chemist. The Volta laboratory was established for the purpose of "prosecuting inventions and researches for their mutual benefit" (Tainter, undated) and was one of the world's first industrial laboratories.

Bell also invested in another research endeavour with proceeds of the Volta prize. Shortly after receiving the prize in Paris, he heard about a young physicist who had a reputation for being an excellent experimentalist. The young man had proposed a simple yet ingenious experiment designed to confirm the existence of ether, a massless medium commonly believed to pervade the universe. Ether had been postulated to exist as the medium for propagation of light waves and gravitational force.

In November 1880, Bell offered Albert A. Michelson $500 to carry out his experiment. By observing the interference of light beams on an optical table that could be rotated in a vat of mercury, Michelson and his colleague Edward Morley, expected to show that light travels more slowly in the direction of the Earth's movement around the sun than when travelling in the opposite direction. The relative motion of the Earth sweeping through the ether would change the apparent velocity of light. What Michelson and Morley found instead, was that the velocity of light was exactly the same no matter what direction it was measured in. This result was in violation of the theory of ether and ultimately was recognized as the first experimental evidence of Einstein's theory of relativity. Michelson won the 1907 Nobel prize in physics for this work.

In terms of the scientific value derived, Bell's support of the Michelson-Morley experiment may represent one of the best placed grants ever for scientific research. In fact, Michelson only used $200 of the $500 Bell had given him. Bell told him to keep the rest for further experiments (Bruce, 1973).

The graphophone

Whatever the Volta associates had in mind when they first formed the laboratory, a potentially money making challenge was proposed by Bell's father-in-law Gardiner Hubbard. An executive of the American Bell Telephone Co., Hubbard and a few business partners had bought the rights to Thomas Edison's phonograph which had been patented in 1877. In its original form, the phonograph was so difficult to use and had such poor sound quality that Hubbard's company, the Edison Speaking Phonograph Co., found itself with a marvelous but unmarketable product. Hubbard, who originally told his son-in-law that he bought the phonograph patent to discourage Edison from pursuing work related to telephony, now urged the Volta associates to improve the phonograph and make it commercially viable (Tainter, undated).

Bell, who had privately expressed great disappointment that he had not been the one to invent the phonograph, now had an opportunity to do to Edison what Edison had done to him with the telephone; take a brilliant but imperfect invention and turn it into a successful product. The Volta associates attacked the phonograph and five years later had developed the graphophone, the first commercially successful sound recording machine. In the graphophone, the tin foil of Edison's phonograph was replaced with wax cylinders resulting in higher fidelity in recording and better durability in playing. Instead of indenting or embossing the recording surface as in the Edisonian phonograph, the recording stylus of the graphophone cut a groove into the wax, removing material from the groove instead of displacing it. Finally, a "floating" or flexible playback stylus was introduced, an innovation that lasted a century in the recording industry.

Optical disc recordings

Now that vinyl records have been replaced with the compact disc, it would seem that the last lingering influence of Edison's phonograph and the Volta laboratory's graphophone have finally disappeared from recording technology. Instead of a groove whose undulating walls physically represent the waveform of the recorded sound, the recording on the surface of a compact disc is represented by a series of microscopic pits that look like the dot-dash pattern of Morse code. A computer in the CD player interprets the digital code and transforms it into the audio signal. Another distinguishing feature of the CD is that it is read optically. A tiny laser inside the CD player is focussed on the surface of the CD and as the disc turns, the light reflected off the series of pits is read by a detector which feeds the digital code into the CD player's computer. Not only can a lot more information be stored on a CD but there is no longer any physical contact between a stylus and the recording surface, so a CD lasts much longer than an old-fashioned vinyl record.

Incredibly, some of the ideas inherent in the CD were actually experimented with by Bell and the Volta associates. They demonstrated and patented a technique to photographically record sound on a glass disc (Bell et. al., 1886). Tainter recorded in his notes (Tainter, 1881) that he recognized the advantages of a disc format recording over the cylinders used in the graphophone because of the possibility it offered to replicate the recordings. A disc recording based on a photographic process would be easy to reproduce and would never wear out due to contact with a stylus, just like today's compact disc.

To record sound using light, the Volta associates used a system of mirrors and a lens to concentrate a beam of sunlight on a vertical glass plate. A fine stream of ink was directed against the glass plate (the ink then dribbled off the plate into a container below). The ink nozzle was fixed to a "sounding board" or small plate which picked up sound vibrations. By speaking loudly at the sounding board, the sound vibrations were transmitted to the nozzle which caused the ink jet to jiggle. The patch of ink on the glass plate therefore oscillated in size and position in accordance with the vibrations of the speaker's voice. By passing the beam of sunlight near the edge of the ink patch, the width of the beam was modulated in a way analogous to the sound vibrations.

The modulated light beam was then focussed onto the surface of a glass disc inside a narrow, light-tight box through a small slit cut in the side of the box. The glass disc was about 35 cm in diameter and was coated with a gelatine-bromide photographic

emulsion. During a recording, the glass disc rotated and simultaneously moved sideways behind the slit so that the light traced out a spiral pattern and intensity fluctuations were recorded photographically along the spiral. That is how the world's first optical recordings of sound were made over a century ago.

Two different methods were used to encode the light variations on the disc. In the "variable density" technique, an image of a slit near the vibrating patch of ink was projected onto the disc. This resulted in a constant width spiral pattern with variations in the degree of exposure of the photographic recording (Fig. 4). In the "variable-area" technique, an image of the edge of the ink patch was projected onto the disc resulting in a jagged, saw-toothed spiral where the sound waveforms are represented by the shape of the pattern on the edge of the spiral (Fig. 5).

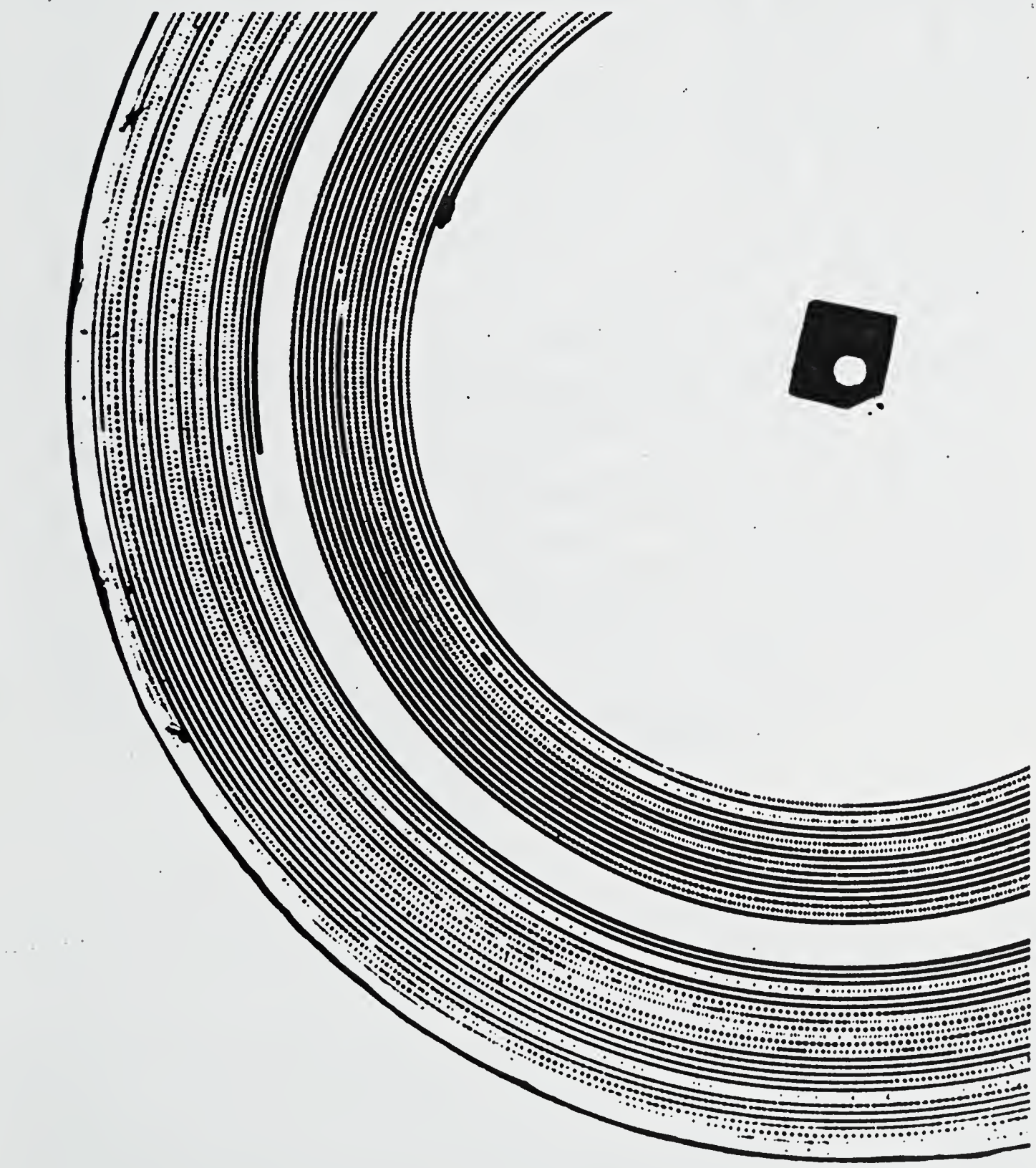


Fig 4 Section of a variable density optical recording. (Courtesy of National Museum of American History)

Fig 5 Section of a variable width optical recording showing waveform of the word "barometer". (Courtesy of National Museum of American History)

Of the 32 patents awarded the members of the Volta laboratory, the patent for the optical recording technique (US patent No. 341-213) is one of only four where Alexander Graham Bell's name appears first, therefore it must have been of special interest to him and was likely his idea (Newville, 1959). However, it is hard to know what the inspiration for this invention was or what the Volta associates thought its potential was, because key notebooks of Sumner Tainter pertaining to its development were lost in a fire (Tainter, undated).

Among Tainter's remaining papers, there is a handwritten script with the following solemn declaration (Harvey, 1982):

> "This recording has been made by Alexander Graham Bell in the presence of Chichester A. Bell on the 15th of April, 1885 at the Volta laboratory, 1221 Connecticut Avenue, Washington D. C. In witness whereof, hear my voice - Alexander Graham Bell."

Whether or not this message was intended for recording on an optical disc is unknown but the date, April 15, 1885, is during a period when the optical recordings were being made successfully and seemed to be the main interest of the laboratory.

The discovery of the above quotation prompted Floyd Harvey of Bell Laboratories to attempt to "play back" some of the better discs in an attempt to find a recording of Alexander Graham Bell's voice. Harvey built an apparatus to scan a beam of light through a copy of some of the discs onto a light detector so as to retrieve the audio signal. Unfortunately, most of the sounds recovered were unintelligible except for one disc which contained the word "barometer" repeated several times. Not only is this single, mundane word disappointing, but there is no indication as to whose voice uttered it. To this day, there are no known recordings of the voice of the man who invented the telephone and contributed greatly to the world's recording industry.

Today, the remaining optical disc recordings are stored at the National Museum of American History, Smithsonian Institution in Washington D. C. Unfortunately, the discs have deteriorated a great deal leaving little hope that any sound that might have been recorded on them can be recovered. However, there are a few discs that are in relatively good condition. Two of these (shown in Figs. 4 and 5)have been copied and replicas of them can be seen at the Alexander Graham Bell, National Historic Site in Baddeck, Nova Scotia.

In November 1885, Chichester Bell decided to return to England thus precipitating the end of the Volta laboratory. Investors, including Bell's father-in-law Gardiner Hubbard, formed the American Graphophone Company and bought the Volta laboratory patents pertaining to the graphophone. Sumner Tainter was hired as chief of research and product development. The optical recording technique was nearly forgotten, but in the 1920's, researchers at the Western Electric Company and Bell Telephone laboratories used the principle described in Bell's expired optical disc patent to create the modern motion picture sound track (Kellogg, 1955).

Aviation

In the summer of 1885, Bell and his family visited Nova Scotia for the first time. They became enchanted with the picturesque village of Baddeck in Cape Breton and, seeking refuge from the terrible heat and humidity of Washington summers, decided to build a summer home nearby. The expansive house which the Bells' called Beinn Bhreagh (Gaelic for "Beautiful Mountain") was soon the center of the family's social life for half of each year.

At Beinn Bhreagh, Bell attacked one of the last great challenges of modern times, the development of, in his words "a contrivance for mechanical manned flight". The realm of cranks and science fiction in 1898, Bell approached the problem of flight by studying the performance of kites. He succeeded in developing some fantastic kite forms (Fig. 6) and did learn how to optimize lift through use of multiple cells based on a tetrahedral unit cell. Unfortunately, Bell did not recognize the obstacle represented by the enormous drag of kites, an obstacle which would render motorized flight impossible.

Fig 6 Kite experiments at Beinn Bhreagh, 1908. (Courtesy of Heritage Canada Alexander Graham Bell National Historic Site)

On December 17, 1903, Wilbur and Orville Wright made the first manned flight in a powered heavier-than-air craft at Kitty Hawk, North Carolina. To safeguard their patent applications, the Wrights kept details of their airplane secret and shunned publicity for nearly two years. Nonetheless, Bell heard irrefutable testimony that the Wright brothers had flown soon after the fact. He accepted the disheartening news and then carried on with the perfection of his tetrahedral kites.

In the autumn of 1906, Bell hired a brilliant young engineer, Frederick "Casey" Baldwin who convinced him to give up the kites and try a winged glider design. Eventually, on March 12, 1908, Casey Baldwin made the first public flight in North America in the biplane "Redwing" (Parkin, 1964). On July 4 of the same year the group, which called itself the Aerial Experiment Association, won the Scientific American trophy for the first flight of one kilometer with a plane called the "June Bug" piloted by Glenn Curtiss. Bell, Baldwin and their AEA associates went on to make significant contributions to aviation including the invention of ailerons, the flaps on the trailing edge of wings, used for lateral control of the aircraft.

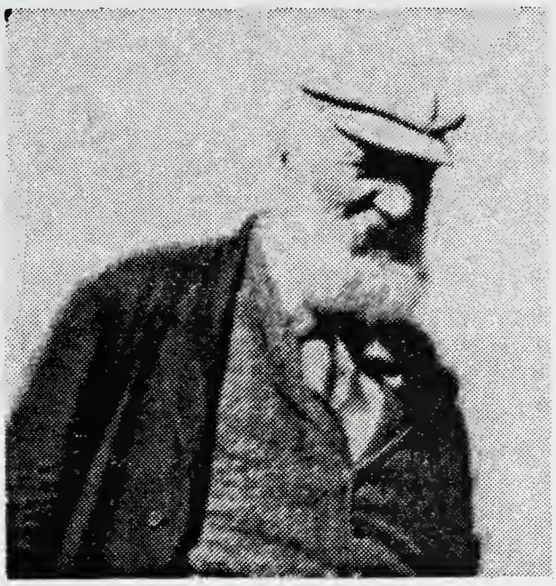
A lifetime of inventing

By the turn of the century, the Gilded Age of Invention was waning, slowly displaced by the modern age of industrial research. For example, at Bell Telephone laboratories, teams of specialists were applying fundamental science to the problems of psychoacoustics, information theory and electrical engineering to develop the world's telephone network. Although Bell often thought of working on improvements to the telephone, he found himself left behind in the technical intricacies of his own invention.

After the aviation work, Bell and Baldwin continued their collaboration at Beinn Bhreagh and went on to develop hydrofoils that streaked across the Bras D'Or lakes, one of which held the world marine speed record of 113 km/hr for ten years. Bell continued to busy himself with many other experiments, intrigues and investigations

at Beinn Bhreagh. At the age of 75 he received his last patents, with Casey Baldwin, for features related to the hydrofoil. Bell died later that year on August 2, 1922.

Today, the kites, airplanes, hydrofoils and other mementos from Bell's Nova Scotia summers can be examined at Heritage Canada's Alexander Graham Bell National Historic Site in Baddeck located within sight of Beinn Bhreagh.



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CHARLES BRENTON HUGGINS
NOBEL PRIZE WINNER MEDICINE 1966

Terry Burns, MCIC

Huggins won the 1966 Nobel prize in physiology for discoveries in hormonal treatment of prostatic cancer. He received the award as a co-recipient with Peyton Rous.

Huggins is a native of Halifax, Nova Scotia, Canada and his complete early- life history up to age 19 show he was Halifax grade schools, mostly in Halifax's south-end. He completed his high school in Parrsboro, Nova Scotia, the home of his mother.

After high school, he went to Acadia University for his B.A., then to Harvard Medical School and he graduated in 1924. Dr. Huggins completed his formal education with a surgery fellowship in Michigan, the home of his wife, Emily Wellman, and finally a tour through Europe and Britain to look at some research in a number of fields. Huggins spent his entire medical research career at University of Chicago and between 1972-1979 he was the chancellor of his beloved alma mater in Nova Scotia, Acadia.

Proclaiming Dr. Huggins achievements at the Nobel award ceremony, it was first noted that he had accomplished 'a new type of cancer treatment, one now assisting previously inaccessible patients with the use of nontoxic, natural hormones rather than toxic or radioactive agents with few side effects. In his address, Huggins said that the control of cancer by hormones can summarized: (1) some cancers differ essentially from the cells they arose in response from a change in the hormone environment; (2) certain cancers are hormone-dependent and these cells die when supporting hormones are removed; (3) certain cancers succumb when large amounts of hormones are administered.

C.B. Huggins a remporté le prix Nobel en physiologie pour sa decourte de traitements par hormones du cancer de la prostate. Il a recu cet honneur en tant que co-décipiendaire avec Peyton Rous.

Huggins est natif d'Halifax, Nouvelle Ecousse, Canada, où il a complete ses etudes primaires et une partie du secondaire. Il a termine son secondaire a Parrsboro, Nouvelle Ecousse, ville natale de sa mere.

Il a poursuivi ses etudes a l'Université Acadie où il a obtenu le diplôme de Bachelier es Arts. Par la suite, en 1924, il a complété ses études en medicine à l'Université Harvard. Quelque temps plus tard il a complete un stage en chirurgie au Michigan, aux États-Un is, endroit ou a grandi sa femme, Emily Wellman. Il a parcouru l'Europe y compris la Grande Bretange afin d'observer et d'évaluer divers projets de recherche dans une dans une variétés-2-de domaines scientifiques.

Huggins a passé toute sa carrière de chercheur medical a l'Université de Chicago. De 1972-1979, il a occupé le poste de recteur à son Alma Mater, l'Université Acadia.

Lorsque on a annoncé les nombreuses réussites du docteur Huggins lors de la cérémonie de présentation du prix Nobel, ou a signalé, entre autres, sa décourte de nouveaux traitements du cancer, traitements dont bénéficient certains malades jusqu'alors. Ces traitements consistent d'utiliser des hormones naturelles et non-toxiques plutôt que les agents traditionnels qui étaient radioactifs et toxiques. Il esrt à noter, de plus, que ces nouveaux traitements ont peu d'effets secondaires.

Dans son allocution, Huggins a déclaré que le contrôle du cancer par hommes peut se resumer ainsi: 1. Certains cancers diffèrent essentiellement des cellules d'où ils proviennent et cela en réponse à un changement dans la composition des hormones qui entourent les cellules. 2. Certains cancers dépendent d'hormones et les cellules en question meurent quand les hormones qui les supportent sont éliminées. 3. Certains cancers meurent lorsque de grandes quantitées d'hormones sont administrées.

Introduction

Dr. Huggins' Early Family History in Halifax

Dr. Charles Brenton Huggins, a Nobel prize winner in medicine and physiology for 1966, was born in Halifax, N.S. on September 22, 1901. His father, Charles Edward Huggins, was a pharmacist and most likely also a Halifax native. Dr. Huggins' mother, Bessie Spencer was from Parrsboro, a community in northwestern Nova Scotia. They were married in Parrsboro on June 26, 1900. Young Chas. B.s' brother, Victor , who was also an M.D., practised in Illinois, U.S.A.

Charles Edward Huggins was a professional pharmacist whose drug store was in downtown Halifax at 151/2 Jacob Street. This downtown Halifax street ran from Brunswick St. due east and down the hill to the harbour, and ending at Upper Water Street. Today, the whole Jacob Street area has been replaced by a large high-rise complex called Scotia Square. The Huggins residence was adjacent to the Jacob Street store, on the corner of Poplar Grove and Jacob.

The Huggins family during the time period from 1886 to roughly 1900 had lived in residences on Maynard and Barrington Streets. The family moved to a south-end address of 5 Brenton Place around 1906 when Dr. Huggins began his elementary education at Morris Street School. Dr. Huggins divided his early education between Morris Street and LeMarchant Street schools. Chas. Edward, practised his profession as a pharmacist in Halifax until his death in 1912.

An advertisement in the Halifax city directory of 1895 for Charles Edward's pharmacy described the range of items for sale "Chas. E. Huggins, Chemist, Depot for Army and Navy Blood mixture and Hele-type Cream; Sponges, Toilet Soaps, Perfumery, etc, Jacob cor with Poplar Grove."

Charles Edward Huggins was very much involved in his own professional organization, the Nova Scotia Pharmacy Association. He held the executive position of secretary in 1901, the provincial vice-presidency in 1902 and the presidency in 1903. An informative booklet put out by the Nova Scotia Pharmacy Association summarized the 50 years of pharmacy in Nova Scotia, 1875-1925.

Charles Edward died at the young age of 43 on April 14, 1912 after only 14 years of marriage. He left a family of two young boys and his wife Bessie. Dr. Huggins was only 11 years old and in elementary school. Dr. Huggins' father is interred in Camp Hill Cemetery.

Following the death of C. E. Huggins, the family moved to Parrsboro where Mrs. Huggins family still lived including her sister, Mrs. Clinton (C.V.) Cook, and brother-in-law, Captain C.V. Cook. The two brothers completed both their elementary and high school education in Parrsboro. Dr. Huggins moved quickly through his high school education at Parrsboro because before that in 1914 he was in Halifax in the middle of grade school and by 1916 at age 14 (born September 22) he was at Acadia. The family lived on Spring St. and Dr. Huggins took an active part in the local Baptist Church's Sunday School as a teacher. Some of the information obtained for this period was attained in conversations with former residents of Parrsboro.

Dr. Huggins seems to have enjoyed his years in Parrsboro in 1966, when the announcement of his Nobel Prize was made, he sent a thank you letter to the Parrsboro town council in response to their earlier note of congratulations, in which, in a very exuberant manner, he wrote, "I love Parrsboro."

At other times in his life Dr. Huggins showed similar loyalty to his native province. He especially loves the Annapolis Valley, the home of his alma mater, Acadia University. Possibly Dr. Huggins went to Acadia because it was close to his home and also because it had a Baptist affiliation. Very possibly Charles Brenton got some sort of scholarship assistance because of his excellent academic ability and his close ties with the Baptist religion. At Acadia he had an interest in a wide range of subjects, especially the classics. He enjoyed the classes of Prof. Thompson, whom he respected and was his classics professor. Dr. Huggins came to the profound conclusion that the Latin poets developed a boy's character, and if a scientist could manage his character he could manage cancer research of world calibre. There are many in agreement with him still today who, not just making a verbal consent, believe that a strong liberal arts education is the basis for a successful career in science and medicine. The skills and

knowledge of all types gained from an earlier liberal arts education complement later work in the field of science.

Dr. Huggins graduated from Acadia with his B.A. in 1920 when he was nineteen years old. Dr. Huggins progressed to Harvard Medical School, and in 1924 he received his M.D. In his own manner, he humbly explained his presence that the exalted University by the fact that the admissions office was still lacking a sufficient number of foreign students when he applied. He completed his internship in surgery in Michigan in 1926.

In 1927 he married Emily Wellman of Michigan who was to be his wife for 60 years. As the first major move in Dr. Huggins' early career he was invited to do research at the University of Chicago under the leadership of Professor Dallas B. Phemister.

Huggins was to spend the whole of his professional life at Chicago. In the 20's Phemister sent him to Europe to get some training in urology. Some of the fundamental facts he learned at European and British research labs were that phosphate esters and phosphatases play an important part in the induction of bone marrow and treatment of prostate cancer. During his travels in Europe he learned from Prof. Otto Warburg the essential principle of tumor growth and that tumor cells, unlike normal cells, obtain energy from the combustion of carbohydrates in the absence of oxygen as fuel.

Huggins' Prostate Cancer Research

As early as 1933, Huggins had made many new contributions to our knowledge of the physiology and biochemistry of the male reproductive tract, and this led to an intensive and successful study of the prostate (Talalay, 1965). Measurements of enzymes in blood serum furnished the proof that cancer of the prostate is hormone-responsive (Huggins, 1965). Also, the study of the physiology of prostatic fluid gave us the first understanding of the relationship of the endocrine system to prostatic function. Thus began Huggins' endocrine theory of prostatic carcinoma. In 1940, he announced that treatment consisting of estrogen doses or orchiectomy surgery could give long term regression of the disease. A large number of patients with advanced disseminated prostatic cancer had so responded. He had found that prostate cancer is often not an autonomous process because the cancer grows or shrinks respectively whether androgens are administered or eliminated (Talalay, 1965).

Huggins produced as evidence of his results, relief of pain and regressions of tumors in far-advanced prostatic cancer patients and those beyond help of any therapeutic measures. In some of these patients were included the regression of mestastases, and many had returned to active and useful lives (Huggins, 1965). The treatments devised by Huggins have been adopted around the world. The significance of the positive results can not be over-emphasized because prostate cancer is one of the most common types of male cancer, especially among older men. It has been stated that, "humanity owes Charlie Huggins a deep gratitude." (Talalay, 1965). In other words of Talalay (Science, 1966), "the award of a Nobel prize to one who has done so much for the human cancer patient is richly deserved".

Talking about the essentials of his prostate cancer methods, Huggins stated, "The method of proof of a proposition can be of greater interest than that which is proved," i.e. one can look at this as similar to the emphasis that the famous French philosopher Descartes put on method over content. The comparison is based on the fact that Huggins' endocrine treatment of prostate cancer was not reached empirically but from an experiment on prostatic (A fruitful interplay: The University of Charles Huggins

1985) physiology. Therefore, both a method of therapy and its mechanism were in one joint study and as a result a rational chemotherapy of cancer was initiated (Talalay, 1965). Estrogens were the first agents of known constitution (except radioactive agents), which helped substantially with cancer, and estrogens became the first non-toxic substances taken by mouth that were beneficial.

Besides being the first positive results in the clinic, the results spurred a major stimulus to all research on cancer chemotherapy. For the first time a large ray of hope appeared in the treatment of cancers because it had been proven that large mestastases could be made healthy by control of the internal environment of the host. The major result clinically has been that the positive effects of estrogens and orchiectomy on cancer of the prostate have been repeatedly demonstrated all over the world. In Huggins' initial series of 20 patients who had large mestastases, four lived more than 12 years. The fact that health could be restored to certain cancer patients, by a change in their hormonal states, led Huggins to conclude (Anonymous, 1985), "Two new principles of medicine emerged from these studies: (1) cancer is not necessarily autonomous and intrinsically self-perpetuating; (2) cancer can be sustained and propagated by hormonal function which is not necessarily abnormal in kind or exaggerated in rate, but which is operating at normal or even subnormal levels. (Talalay, 1965 [p. 1139])

In 1939 Huggins had surgically isolated the prostate gland of dogs. By analyzing the quantitative and chemical composition of canine prostatic secretions under different hormonic conditions, (Talalay, 1965) he found that testosterone stimulates the growth and secretary activity of the prostate. He also learned that estrogen, the female sex hormone, inhibits prostate growth.

In 1945 Huggins and two students, C.V. Hodges and W.W. Scot, with the basic problems of prostate cancer in mind, found that testosterone promoted the growth and mestastized the cancer whereas estrogen or castration helped in the reduction of the cancer, but hormone treatment only checked the growth of prostate cancer temporarily (Nobel Prize Winners, 1987). This discovery brought Huggins the 1966 Nobel Prize in medicine. Also, referring to castration, it was a better form of treatment and after seven years the patient was cancer free. In the history of cancer treatment, as early as 1896, Beatson, prior to any concept of hormones, used mastectomy (ovariectomy) to induce the regress of breast cancer in a few women. Any future hope for Dr. Huggins in his field of expertise, hormonal treatment, was not good because mammary cancer rarely responds to such treatment.

A further experiment in 1945 by Huggins came after the failure of antiandrogen measures, and it became clear that the adrenal glands were a source of growth-promoting steroids to maintain the activity of the prostatic cancer after the removal of the testes. This conclusion was reached because both castration and estrogen therapy still required the removal of the testosterone source, the adrenal glands.

He performed the first bilateral adrenalectomy in man in the pre-cortisone era and the results, although minimal, proved to be significant in later development of the cancer therapy (Science, 1966). He replaced the normal function of the adrenal glands with cortisone. Huggins abandoned the cortisone procedure until replacement therapy became available. He found that the hormones formed in the gonads to sustain mammary and prostatic cancers are also formed in the adrenal cortex.

The attitude of Huggins' medical research colleagues around the world toward his success and good judgment, as related to adrenaloctomy, is given by Sir Stanford Cade, "His (Huggins') genius in physiological research, his surgical courage, and skill led him to try adrenaloctomy in advance of the discovery of cortisone, only to abandon it until replacement therapy became available,...". (Talalay, 1965).

Huggins' major contribution was that he was the first to develop practical processes to suppress aggressively and limit the growth of cancers. However, he was not the first to observe that some cancers of the prostate shrivel when certain procedures are done with the source of the hormones. Huggins prolonged the lives of millions of people through the use of male and female hormones to treat their cancers without surgery. He also used synthetically produced variants of the natural hormones that had little female or masculine effects on either type of patient. To put Huggins' role in perspective, Dr. Rous of the N.Y. Rockfeller University said that he personally had done nothing practical to cause him be the co-recipient with Huggins of the 1966 Nobel in medicine prize. They worked in the same field, but his successes were not able to be applied as easily as the work of Huggins to the saving of innumerable people.

The first pharmacological estrogen preparation used in the clinical treatment of cancer was diethylstilbestrol. This was the beginning of the chemotherapy of cancer (Huggins, 1965). But, in his research Huggins used phenolic estrogens and orchiectomy with human prostate cancer as with dogs' prostate cancer.

Measurements of phosphates in blood serum proved that cancer of the prostate in man is hormone-responsive. The testing level that Huggins used to come to this conclusion was that he measured the blood levels of an acid-phosphate secreted by prostate and alkaline-phosphatase secreted by bone-forming cells in bone tissue. Both of these substances are in high concentration in the blood of patients with mestastic cancer of the prostate . He concluded that the level of the enzymes in the blood provides a useful index of the cancer's activity and the efficacy of the treatment.

Beginning in 1950, Huggins spent 15 years developing a model for human mammary cancer. It took a long time to induce mammary tumors in animals, and the lesions did not show any susceptibility to hormones. These obstacles prevented any good results in this type of cancer. In the early 1960's he found that a single dose of DMBA (7,15-dimethylbenz(a)anthracene), a polycyclic aromatic hydrocarbon (PAH's), can evoke in a few weeks malignant tumors, many of which are hormone-dependent. The tumors grow or shrink in response to the steroidal balance of the host. They also grow faster during pregnancy and with the injection of progestational steroids. A combination of estrogen and progesterone for a limited time caused permanent regression of one-half of these tumors . Similar regime gave worthwhile relief to some women with disseminated carcinoma of the breast.

A study of the nature, structure, and electronic nature of PAHs show which molecular properties selectively induce mammary cancer. All PAHs' are flat with conjugated double bonds and include special substituents of methyl or amino groups or more aromatic rings. They form colored complexes with electron-acceptors of a charge-transfer type.

Further observations showed that powerful electron acceptors also induce a high incidence of mammary cancer. However, carcinogenicity is not dependent entirely on these factors but also on the size and steric configuration of themolecule is critical. Three types of carcinogenic molecules with similar molecular geometry are certain steroids, carcinogeni chydrocarbons, and hydrogen-bonded base pairs in DNA (Talalay, 1965). Molecular models reveal these similarities very neatly since the molecules fit into a hexagonal box moulded around the base pairs of DNA. The box is not only beautiful but also utilitarian. (AUTHOR'S NOTE: Since Huggins accomplished this work, I suspect that great advances have been made in this area including more precise knowledge of many structural and steric factors, allowing the use of computers with 3-D imagery.) The model suggested that the interaction of PAHs' with nucleotide base pairs may be important in the induction of mammary cancer. To

understand the carcinogenic power of PAHs', we must understand that these hydrocarbons masquerade as hormones or heredity material.

The fact that hormones influence the growth of cancer came initially from the study of tumors of dogs initially, not man, It came and indirectly through a series of observations involving metabolism and endocrinology.

The second quarter of our 20th century found the medical researchers interested in two topics : (1) isolation of steroids; (2) the biochemistry of organic compounds containing phosphorus, an element described as a 'soft atom'. The key to the steroid hormone problem in cancer was the isolation of crystalline estrone from the urine of pregnant women. In the phosphorus field there were important discoveries of hexose phosphates, nucleotides, and high-energy phosphates intermediates.

Remarkably, it was found that spermatote fluid is devoid of acid-soluble phosphorus and free hexose, but human semen contains large amounts of inorganic phosphorus and the carbohydrate, fructose (hexose, ketose). When a human male ejaculates, the environment of the spermatoza is altered by a sharp rise of fructose and soluble phosphorus. Huggins found (Talalay, 1965) that while seminal vesicles in man are the chief sources of the semen components, unmixed secretions of a human's various sex glands are difficult to obtain.

Conclusion

Huggins has accomplished a great amount both in research and in clinic, and as a result has prolonged many lives. On September 22, 1996, he was 95 years old; that same year was also the 30th anniversary of his Nobel prize in medicine. I strongly urge that all Canadians, all Nova Scotians and all Haligonians should warmly congratulate Dr. Huggins , a native son, on his achievement and feel the association with him as a world-class medical researcher. Dr. Huggins made his first significant contribution to medical research by showing the influence on bone formation. This was in his first year (1927) at the University of Chicago Medical School, and it fueled his commitment to research and discovery for his entire career.

Dr. Huggins left Nova Scotia when he was 20 years old, but he has returned many times especially during the period 1972-79 when he was the Acadia University Chancellor. He has relatives here and has made visits to Parrsboro and Chester over the years.

Throughout the medical world many of the discoveries of Huggins are used and in the many awards he has received we see the degree and magnitude of his life's work. Nova Scotians are extremely proud of their sons and daughters who have risen to a world class status, and I think no event would better exemplify that pride than the day in 1946 when Cyrus Eaton, Dr. Huggins and a clergyman, Rev. A.H.C. Morse, all received honorary doctorates from Acadia. A book by Dr. Allan Marble, who is simultaneously a professor at both Dal and TUNS universities, which is called "Nova Scotians at Home and Abroad" lists many world-level scholars, who are mostly native-born persons including Dr. Huggins.

Dr. Huggins, from my research, is the only person in eastern Canada or east of Quebec who has received a Nobel prize.

To exemplify Dr. Huggins accomplishments in another manner we will list the more important of his many awards:

(A) 1969- One of 'The 1000 Makers of the 20th Century' Sunday Times, London.
(B) 1966- Nobel prize in medicine. NOTE. Huggins lab is part of University of Chicago and that institution has collected 24 Nobel prizes over 95 years.

(C) 1963- Lasker Chemical Research Award- one of the highest awards to be awarded in American medicine; co-recipient with Dr. DeBakey. This award is give for "the highest achievement in the application of biological science to human welfare."
(D) 1943- C.L. Mayer Award from National Academy of Sciences; First recipient.
(E) 1936 and 1940- twice received gold medals from AMA.
(F) 1909- Emil Kocher was the only other surgeon to receive a Nobel prize up to 1966.
(G) 1963- Another award the very next day after award (c) from American College of Surgeons

It was an honorary fellowship from the American College of Surgeons. He received this award because he "rightly earned the highest distinction which can be bestowed by the Surgeons of Canada and the United States". Besides these awards, Dr. Huggins was the first to pioneer many different and effective medical procedures :

(A) 1927- Demonstrated the direct influence that heat had on blood formation in the bone.
(B) 1938- Focused on cancer of the prostate; discovered the hormone dependency of prostate cancer and found the first effective treatment of the disease.
(C) Discovered that androgens stimulated cancer, whereas castration or estrogens slowed it down; found that cancer can be dependent on hormones for metabolism ; his major contribution on prostate cancer was that orchiectomy or small doses of phenolic estrogens relieved pain and reduced size of the tumor; an alternate treatment was the use of synthetic or natural estrogens.
(D) Created a method of treatment of breast cancer which included the removal of the adrenal glands; this was, in 1951, an advance in treatment.
(E) Devised a much quicker method to develop breast tumors in lab animals; the PAH type-molecule, DMBA, induced breast cancer while ovarian hormones suppressed DMBA-type cancers.
(F) Seven sorts of hormone-responsive cancers of humans and animals have been treated across the world by this system including : cancers of the prostate, breast, endometrium, thyroid, lymphatic system, kidney, and seminal vesicle. Huggins also worked in the following areas and made original contributions; bone formation, bone marrow, serum enzymes, protein chemistry.

Huggins has accomplished a great deal in the area of clinical physiology, and he has a large number of 'firsts' in medicine to his credit. But equally intriguing is his philosophy, for his very successful life, which included such principles as, "It is a pleasant vocation to do experiments while teaching young people how to find new and beautiful things- how to do elegant science." (Huggins, 1965).

Another quote explains his love of science and details the qualities of science which make it mysterious and interesting: he stated that Science is pre-set to give only the truth" (Huggins, 1965). As many young graduate science students have found out, Huggins describes such students as very hard workers , full of enthusiasm, and the full bloom of these characteristics is limited to the age range of 18-32.

He is famous for the statement, "Discovery is our business." The adjective "our" tells the fact that the only economic procedure is by working entirely as a group. Also, two other rules for the effective use of student research time are that the overall objective is that no one is responsibility-free, and that these years are excellent ones to learn science.

Huggins continues and tells us that a researcher must be able to recognize an essential problem, and that usually a talented student has such as an inborn ability. A noble problem is one which gets things moving during its period or time. What problems a researcher spends his time on do not need to be dictated by the requirements of the people, but certainly for the good of mankind a medical problem should have priority. This was said by a man who fell in love with medical research and who regarded science as the art of our age. Huggins' Nobel award was the first for cancer research by 1966.

Although many different directions can be taken, the problem in science is solved in only one way, and this direction is simple and comprehensive. The only possibility of success in research is to look at science being ruled by a combination or duumvirate of idea and technique (or substance and accident, essence and form).

Finally, Huggins gives some sensible advice related to the time to make a decision to set the problem aside. He says that the law of diminishing return is one good criteria on, and he also compares Heisenberg's principle concerning the lack of ability to know both the position and velocity of an electron with the fact that when the researcher starts to get close to a final answer the solution becomes evasive. This is a good indicator that it is time to move on.

Dr. Huggins has worked very hard for 70 years, but his objective over this long time was not to amass a fortune of money but to do research, "Research is not work to me. It is my pursuit and pleasure." (Medicine on the Midway Fall, 1985) He worried that too many doctors have an objective of high income, and this distracts them from research.

(NOTE FROM AUTHOR: Everyone talks about coincidences in their lives, but I think I met the absolutely extreme example when doing research for this paper . In one of the Dalhousie professional school libraries I had a chat with the librarian, and the net result of our conversation was for me to learn that she was working in University of Chicago on the very October day in 1966 when Dr. Huggins heard the news. She also assisted Mrs. Huggins manning the telephones.)

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(AUTHOR'S NOTE The Burns family's great-grandfather, John Burns, who is buried in Holy Cross Cemetery on South Park St. and is (our 4th generation relative) in Halifax resided at 151/2 Brunswick St. during the exact period that the Chas. Edward Huggins family was at 151/2 Jacob St., that was roughly, 1880-1895. These two residences were about 3-4 blocks apart north-south on Brunswick St.)

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COLUMELLA EDENTULA (DRAPARNAUD, 1805) (PUPILLIDAE), A NEW ADDITION TO NOVA SCOTIA'S TERRESTRIAL MOLLUSC FAUNA

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Four specimens of *Columella edentula* (Draparnaud, 1805) (Mollusca: Pupillidae), a snail species previously unreported in Nova Scotia, were collected in July 1995 near Garbarus Bay. This extends the species range into Nova Scotia from the Magdalen Islands in the northwest, from Labrador in the north, and from the United States in the south.

Four specimens of *Columella edentula* (Draparnaud, 1805) (Fig. 1) were collected in a moist meadow near Garbarus Bay, Nova Scotia (45°53'8", W60°8'28"), on 27 July 1995. The site of collection is an old field in an early successional phase and contains grasses, sedges, rushes, goldenrods, and alders. Along with the specimens of *C. edentula*, four specimens of *Catinella avara* (Say, 1824) and three unidentified specimens belonging to the genus *Succinea* were collected. The four specimens of *C. edentula* represent the first collection of the species in Nova Scotia (Davis, 1985, 1990, 1992) and extend its range into the province from the Magdalen Islands in the northwest, from Labrador in the north, and Pennsylvania in the south (Pilsbry, 1948). Thus, *C. edentula* is now known to occur in Canada from Vancouver Island east to Labrador, the Magdalen Islands (Pilsbry, 1948), and Nova Scotia. In the United States it occurs south to Alabama (Pilsbry, 1948). A description of the specimens collected follows.

Description: Shell cylindrical, tapering towards rounded apex, perforate, juveniles with 4 1/4-4 3/4 whorls, adult with 5 1/2 whorls; thin; light cinnamon, whitish streaks visible on the adult shell and on the apex of the largest juvenile shell; glossy; smooth both with irregular growth lines; sutures deeply impressed. Aperture rounded, truncate by the preceding whorl, with no lamellae. Peristome thin and sharp, with reflected columellar margin. Shell heights (in mm) of the four specimens collected: adult: 2.5; juveniles: 1.2, 1.6, and 1.7.

Pilsbry (1948) in his treatment of *C. edentula* in North America notes that specimens examined were all smaller and with smoother surface sculpture than the typical European form and that they resembled the form *simplex* (Gould, 1841) from New York State and Vancouver Island. Paul (1975) and Kerney and Cameron (1979) reported on the genus *Columella* in Britain and Northwest Europe and include *Columella aspera* Walden, 1966, as distinct from the typical *C. edentula*. In the past these two species have been commonly confused; *C. aspera* is smaller than *C. edentula* but less polished in appearance due to numerous, close-set growth ridges.

A morphologically closely related species that exists in Nova Scotia, *Pupilla muscorum* (Linné, 1758), can be differentiated from *C. edentula* by its larger size (shell height = 3.2-4 mm), its greater number of whorls (up to 7 1/2) and its less impressed sutures (Burch, 1962). *Pupilla muscorum* has been found in mainland Nova Scotia (Davis, 1985, 1990, 1992) but not in Cape Breton (MacMillan, 1954).

A high proportion (40%) of Nova Scotia's terrestrial molluscs have European affinities including 16% Holoarctic and 24% introduced Palaearctic forms (Davis,

1992) and it may be difficult to determine the affinity of a particular species. The new record of *C. edentula* provides opportunities for further comparative studies of North American and European material that could contribute to a better understanding of the origins of the Nova Scotia malacofauna.

The specimens of *C. edentula* described herein have been deposited in the Nova Scotia Museum of Natural History Mollusca Collection in Halifax, Nova Scotia (Nos. Z13946-Z13949). Acknowledgements: We would like to thank Dr. Derek Davis (retired from the Nova Scotia Museum of Natural History) for confirming the identification of the specimens, Mary (Pixie) Williams (Port Morien, N.S.) for introducing us to the collection site, Basma Kavanagh for the illustration, and the Natural Sciences and Engineering Research Council of Canada and the University College of Cape Breton for financial support.

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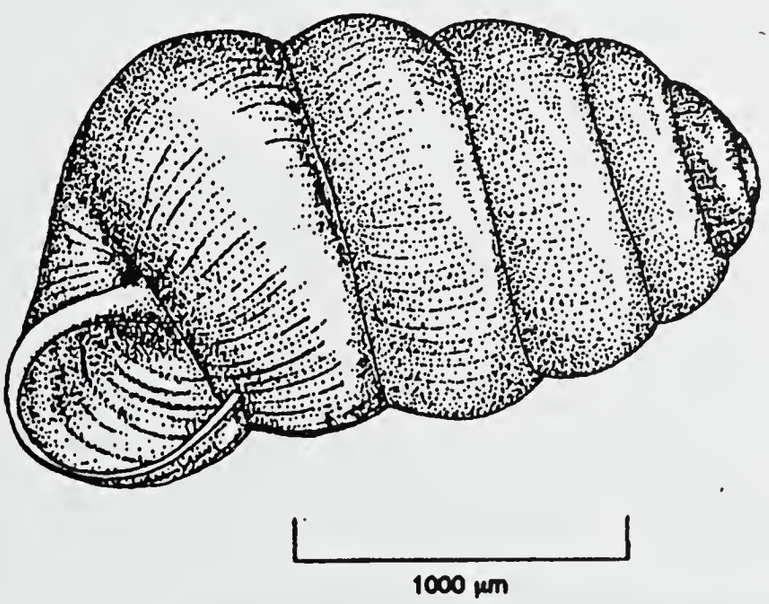

Fig 1 Adult *Columella edentula* (Draparnaud, 1805) (shell length = 2.5 mm) collected near Gabarus Bay, Nova Scotia, on 27 July 1995.

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Studies on the Phytoplankton and the Water Quality at Greenfield, CLWYD, U.K.

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A study of the phytoplankton of the Welsh Dee Estuary, a part of Liverpool Bay, is reported. Correlative studies of the phytoplankton and its biomass with those of the chemical parameters indicated relationships between periodicity of phytoplankton and water quality and the possible utilization of nutrients and some trace metals by the algae. The phytoplankton biomass judged by chlorophyll content ranged from 1.63 to 4.28 mg L-1. The species diversity, of the phytoplankton varied from 2.33 to 3.98 characteristic of the oceanic plankton. The water quality was found to be within acceptable limits.

Introduction

Burrows and Sharples (1972, 1973), Sharples (1972) studied the phytoplankton of the Liverpool Bay and Mersey estuaries. The working party report on sludge disposal in Liverpool Bay (W.P. Report, 1972a, 1972b) indicated that there should b e aregular programme to monitor the quality of sea water across the sludge dumping area and specifically to measure salinity, temperature, nutrients, plant pigments and quantitative floristic records of the phytoplankton. This paper reports data on the phytoplankton population and the physico-chemical quality of water collected in the spring summer and fall of 1974 in the Dee estuary near Greenfield, North Wales*.

Materials and Methods

Water and phytoplankton samples were collected on eight days at intervals of about one month at Station G, off shore near Greenfield (53° 18'N, 3° 13'W, Fig 1), between April and October. The surface water samples were collected at 30 minutes or 1 hour intervals to represent a part of the tidal cycle. The water samples were taken from a depth of 0.2 to 1.2 m from the surface when the tide was high but during low tides the depth of the samples was just a few centimeters.

Fig 1 Map of Dee estuary and surrounding waters.

* Full details of the results of chemical analyses, the taxonomy of the phytoplankton collected and the seasonal changes observed in this population are given in a Ph.D. thesis (Sita Devi, 1980) which can be consulted at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia, B2Y 4A2.

Surface water samples were analysed for physical and chemical parameters by the Dee and Clwyd River Division (H.M.S.O. 1972). Methods of analysis of chlorophyll-α and phaeopigments (Strickland and Parsons, 1972) ammonia N and trace elements (Sita Devi, 1980) have been reported. The standard membrane filter technique was used for the detection of *Escherichia coli* (H.M.S.O. 1969).

The phytoplankton collection, fixation and enumeration were made on water samples (1L) as previously described (Sita Devi and Lakshminarayana, 1989). For benthic algal examination, mud samples were collected from exposed surfaces at low tide using a 2 cm diameter polyethylene cylindrical corer.

Additional data, analysis results and details of isolation of all phytoplankton collected, are given in supplementary material in the version of this paper on magnetic disc. This data is in tabular form, each table is numbered consecutively and all these tables are referred here in the format: Table XX*

Table I Water quality at Station G near Greenfield, Dee Estuary, U.K.

Characteristic	Units	Mean Value (S.D.)	Range	No. of Analyses
Temperature	deg. C	13.95 (3.2)	9.6 -18.3	50
pH	-	7.65	6.7 - 8.4	45
Salinity	o/oo	30.09 (2.85)	18.2 -33.2	51
B.O.D.	$\mu g\ L^{-1}$	3.7 (2.150)	0.8 -11.7	49
Dissolved oxygen	$\mu g\ L^{-1}$	8.26 (3.5)	1.6 -10.6	8
Phosphate	$ng\ L^{-1}$	8 (2)	0.007- .011	7
Ammonia nitrogen	$\mu g\ L^{-1}$	0.21 (0.12)	0.08 - .51	20
Silicate	$\mu g\ L^{-1}$	0.4 (0.4)	0.07 - 2.3	39
Total iron	$\mu g\ L^{-1}$	1.53 (0.9)	0.21 - 4.14	51
Soluble iron	$\mu g\ L^{-1}$	0.14 (.04)	0.11 - 0.21	6
Total manganese	$\mu g\ L^{-1}$	0.13 (.03)	0.1 - 0.18	32
Total Zinc	$\mu g\ L^{-1}$	0.24 (0.16)	0.05 - 0.98	51
Soluble Zinc	$\mu g\ L^{-1}$	0.13 (0.14)	0.03 - 0.86	45
Chlorophyll	$\mu g\ L^{-1}$	2.43 (1.31)	0.06 - 5.41	51

Results

Physico-chemical characteristics of the water samples. Analyses of water samples collected at station G near Greenfield are given in Table I. As expected water temperatures rose in April and declined in September. In addition to the determinations given in Table I analyses for nickel and cobalt gave values of about 0.2 $\mu g\ L^{-1}$; copper concentration were lower (~ 0.1 $\mu g\ L^{-1}$) and cadmium values lower still (~20 $ng\ L^{-1}$). No correlation was observed between cadmium concentration and the tidal cycle and no changes were found in the copper, chromium and lead concentrations throughout the experimental period. Except for manganese and the elements quoted in the preceding sentence, the concentrations of trace elements were lower in summer than in spring.

A comparison with analyses of Irish Sea waters by other workers is given in Table IV*

Table II Monthly cell numbers, species identified and diversity indices for phytoplankton of the Dee estuary near Greenfield, North Water, U.K.

Date of Sampling (1974)	Mean number of species	Diversity (d)	Mean cell number L-1 ($x10^3$)	Mean chlorophyll-α ($\mu g\ L^{-1}$)
9, April	65	3.9875	81.2	1.84
7, May	72	3.0178	241.0	2.91
22, May	64	3.0089	306.0	4.28
28, June	52	3.2097	300.0	2.38
18, July	57	3.9804	276.0	2.85
15, August	42	2.3326	118.0	3.71
8, September	51	3.4468	105.0	1.63
15, October	49	2.9651	70.7	2.30

Table III Correlation coefficients between phytoplankton chlorophyll–a and physico–chemical parameters of water collected near Greenfield, North Wales, U.K.

Parameters	Log Phytoplankton cell numbers	Chlorophyll-a	Tidal Height	Silicate	Salinity
D. oxygen	-.629	.736	-	-	-
Chlorophyll-a	-.554	-	.547	-	-
Salinity o/oo	-	.519 (.669#)	(.733#)	-.811	-
Total iron	-.658#	.531 (-.822#)	.657#	-	-0.614
Plankton No.	-.647#	.577 (.909#)	-.725#	-	-
B.O.D.	-	-	.543	.692	-
Ammonia (N)	-	-	.578	-	0.673
Soluble iron	-	-	-	-0.596	-
Silicate	-.561#	-	-	-	-0.810
Phosphate	-	-	-	-	-0.673
Soluble zinc	-.511*	-	-	-	0.519

Correlation coefficients for parameters on samples taken in spring.
* Correlation coefficient for total zinc of samples collected in spring.

Composition and variation of the phytoplankton

In all 122 species of phytoplankton representing 108 Diatoms, 12 Dinoflagellates, 1 Hapatophyceae, and one representing the Prasinophyceae were counted. Diatoms, with 48 genera, formed the dominant part of the phytoplankton especially in April alternating in dominance with an unidentified microscopic algal group which was prevalent in October. The Summer and Spring phytoplankton changes in the Dee Estuary resemble that of the Irish Sea (Sita Devi, 1980). Blooms of *Phaeocystis pouchettii*, were observed during May (148,560 bladders L^{-1}) and July (120,690 bladders L^{-1}). the Dinoflagellates were the third important group contributing to the total phytoplankton. They were represented by 8 genera. During August this group increased in prevalence due to a bloom of *Noctiluca scintillans*. The maximum number of cells of this species recorded was 68,490 L^{-1}. A list of phytoplankton in alphabetical order (Table V*) and a list of those organisms that have been reported by other workers

Table IV Water Quality* at Station (G) Greenfield, Clwyd, U.K., Irish Sea and English Channel (*Excepting Water Temperature, pH, and Salinity all other parameter results are expressed in μgL^{-1} - Mean Values) at Station G Greenfield Dee Estuary, U.K.

ParameteR	Dee Estuary Greenfield Present Study	River Dee Queens ferry 1966-71 (1)	River Dee Queens ferry 1970-71 (1)	Liverpool Bay (2)	Liverpool Bay (3)	More-con BE-Bay (3)	North East Irish Sea (3)	Cumberland Coast (3)	Cardigan Bay (3)	Western English (4)
W.T. (deg.C)	13.95	10.9	10.5	-	6.13-14.0	5.76-5.77	5.8-7.96	10.0-12.0	11.0-14.0	11.14-18.65
pH	7.65	-	-	-	-	-	-	-	-	-
S $^{o}/_{oo}$	30.09				30.9-34.46	30.44-31.14	29.75-34.15	30.6-33.1	33.2-34.4	35.17-35.41
D.O.	8.26	9.8	9.6	-	-	-	-	-	-	-
B.O.D.	3.7	3.5	3.9	-	-	-	-	-	-	-
Si	0.39	3.8	3.9	0.25	0.3-16.7	11.9-12.2	5.3-14.4	-	1.0-3.0	0.05-2.64
NH_3-N	0.21	0.55	0.58	0.22	-		-	-	1.0-7.0	0.05-2.25
PO_4-P	0.008	0.63	0.56	0.065	0.25-1.16	1.14-1.19	0.59-1.98	0.1-3.0	0.1-.4	0.05-0.38
Fe(T)	1.53	1.85	1.14	-	-	-	-	-	-	-
Mn(T)	0.1	0.13	0.13	0.002	-		-		-	-
Zn(T)	0.24	-	-	0.1	-	-	-	-	-	-
Cu(T)	0.1	-	-	0.002	-	-	-	-	-	-
Pb(T)	0.1	-	-	0.0008	-	-	-	-	-	-
Cd(T)	0.04	-	-	0.001	-	-	-	-	-	-
Ni(T)	0.19	-	-	0.0009	-	-	-	-	-	-
Co(T)	0.15	-	-	-	-	-	-	-	-	-

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Table V List of Phytoplankton Recorded at Greenfield (G), Clwyd, U.K.

BACILLARIOPHYCEAE
Order: BACILLARIALES
Sub-order: Coscinodiscineae
Family: Coscinodiscaceae
Melosira Agardh
M. nummuloides Agardh; SP, S, A, N.
M. juergensii Agardh; SP, S.
Paralia Heiberg
P. sulcata (Ehrenberg) Cleve; SP, S, N, D.
Cyclotella Kutzing
C. striata (Kutzing) Grunow in Cleve & Grunow; SP, S, A, O.
C. Sp.; SP, S, A.
Stephanodiscus Ehrenberg
S. rotula (Kützing) *comb. nov.*; S. A. sD.
Coscinodiscus Ehrenberg
C. radiatus Ehrenberg; SP, S, sD.
C. lineatus Ehrenberg; S, sD.
C. marginatus Ehrenberg; SP, S, A, O, D.
C. concinnus Wm. Smith; SP, sD.
C. grani Gough; SP, S, N, D.
C. eccentricus Ehrenberg; SP, S, sD.
Actinocyclus Ehrenberg
A. octonarius Ehrenberg var. *Octonarius*; SP, S, N, D.
A. roperi (de Brebisson) Grunow; S.
Roperia Grunow
R. tessellata (Roper) Grunow ex Van Heurck; SP, S, sD.
Thalassiosira Cleve
T. nordenskioldii Cleve; SP, S, D.
T. hyalina (Grunow) Gran.; SP, S.
T. gravida Cleve; SP, B.
T. decipiens (Grunow ex Van Heurck) Jorgensen; S.P, .S
T. condensata Cleve; SP, S, A, sD.
Hyalodiscus Ehrenberg
H. scoticus (Kutzing) Grunow; SP, S, O, sD.
Podosira Ehrenberg
P. stelliger (Bailey) Mann; SP, S, A, T, D.
Skeletonema Greville
S. costatum (Greville) Cleve; SP, S, A, N, D.
Stephanopyxis Ehrenberg
S. turris (Greville) Ralfs in Pritchard; SP, A, N.
Family: ACTINODISCACEAE
Actinoptychus Ehrenberg
A. senarius (Ehrenberg) Ehrenberg; SP, N.
Sub-order: BIDDULPHINEAE
Family: BIDDULPHIACEAE
Biddulphia Gray
B. aurita (Lyngbye) de Brebisson; SP, S, D.
B. rhombus (Ehrenberg) Wm. Smith forma *rhombus*; S, A, N.
B. regia (M. Schultze) Ostenfeld; SP, S.
B. mobiliensis (Bailey) Grunow ex Van Heurck; S, N.
B. sinensis Greville; S, A.
B. laevis Ehrenberg; S, L.
Eucampia Ehrenberg
E. zodiacus Ehrenberg; SP, S, A, sD.
Triceratium Ehrenberg
T. favus Ehrenberg; SP, S, N.
Ditylum Bailey

D. brightwellii (T. West) Gronow ex Van heurck; SP.
Bellerochea Van Heurck
B. malleus (Brightwell) Van Heurck forma *malleus*; SP, S, A, N, D.
Family: CHAETOCERACEAE
Chaetoceros Ehrenberg
C. boreale Bailey; SP, S, A, B.
C. densum Cleve; SP, S, A, O, D.
C. danicum Cleve; SP, S, N, D.
C. decipiens Cleve; SP, S, A, Ar.
C. lorenzianum Grunow; S, A, N.
C. constrictum Gran; SP, S, N.
C. laciniosum Schutt; S, N.
C. debile Cleve; SP, S, N, sD.
Sub-order: RHIZOSOLENINEAE
Family: BACTERIASTRACEAE
Bacteriastrum Shadbolt
B. hyalinum Lauder; SP, S, A.
Family: LEPTOCYLINDRACEAE
Leptocylindrus Cleve
L. danicus Cleve SP, S, A, N.
L. minimus Gran; S, N.
Guinardia H. Peragallo
G. flaccida (Castracane) Peragallo; S, A, N.
Schroderella Pavillard
S. delicatula (Peragallo) Pavillard; SP, S, N.
Lauderia Cleve
L. borealis Gran; SP, S, A, N.
Family: RHIZOSOLENIACEAE
Rhizosolenia Brightwell forma
R. alata Brightwell forma *alata*; S, O, sD.
T. delicatula Cleve S, N.
R. stolterfothii H. Peragallo; SP, S, N, sD.
R. robusta Norman ex Pritchard; SP, O.
R. shrubsolei Cleve; SP, A, N.
R. setigera Brightwell; SP, S, N, SD.
R. styliformis Brightwell; SP, S, O, D.
R. hebetata forma *semispina* (Hensen) Gran; S, O.
Sub-order: FRAGILARINEAE
Family: FRAGILARIACEAE
Fragilaria Lyngbye
F. pinnata Ehrenberg; SP, S, L. sD.
F. oceanica Cleve; SP, S, L, Ar, sD.
F. hyalina (Kutzing) Grunow ex Van Heurck; SP, S, O.
F. schulzi Brockman; A, L.
F. crotonensis (A.M. Edwards) Kitton; SP, S, A.
Rhaphoneis Ehrenberg
R. surirella (Ehrenberg) Grunow ex Van Heurck; SP, S, A, O.
Asterionella Hassall
A. japonica Cleve & Moller ex Gran; SP, S, N, D.
Synedra Ehrenberg
S. affinis Kutzing; S, L.
S. tabulata (Agardh) Kutzing; SP, S, A.
S. pulchella Kutzing; SP, O.
S. undulata (Bailey) Gregory; SP, S, N.
Thalassionema (Grunow) Hustedt
T. nitzschioides Hustedt; SP, N, sD.
Licmophora Agardh
L. gracilis (Ehrenberg) Brunow var. *gracilis*; SP, S, A.
Grammatophora Ehrenberg
G. marina (Lyngbye) Kützing; SP, S, A, L.

Sub-order: ACHNANTHINEAE
Family: ACNANTHACEAE
Achnanthes Bory
A. brevipes Agardh;
SP, S, A, L.
A. Sp.;
S, A.
Cocconeis Ehrenberg
C. scutellum Ehrenberg var. *Scutellum;*
SP, S, U.
C. placentula;
SP, S.
Rhoicosphenia Grunow
R. curvata (Kutzing) Grunow;
SP, S.

Sub-ordr: NAVIUCULINEAE
Family: NAVICULACEAE
Navicula Bory
N. crucigera (Wm. Smith) Cleve;
SP.
N. salinarum Grunow;
SP, S.
N. digito-radiata (Gregory) Ralfs in Pritchard;
S, A.
N. viridula (Kutzing) Kützing;
SP, S, A.
N. lyra Ehrenberg;
S, L.
N. cincta (Ehrenberg) Van Heurck;
S.
N. cryptocephala Kützing;
SP, S.
Dipleneis Ehrenberg
D. elliptica (Kutzing) Cleve;
S.
D. didyma (Ehrenberg) Cleve;
SP, S, A.
D. bombus (Ehrenberg) Cleve;
SP, S.
Pinnularia Ehrenberg
P. Sp.
SP.
Pleurosigma Wm. Smith
P. normanii Ralfs in Pritchard;
S, A.
P. aestuarii (de Brebisson ex
P. angulatum (Quekett) Wm. Smith;
SP, S.
Gyrosigma Hassall
G. Wansbeckii (Donkin) Cleve;
SP, S, A.
G. balticum (Ehrenberg) Cleve;
S, O.
G. fasciola (Ehrenberg) Cleve;
S.
Amphiprora Ehrenberg
A. alata (Ehrenberg) Kutzing;
SP, S.
A. paludosa Wm. Smith;
SP.

Family: GOMPHONEMACEAE
Gomphonema Hustedt
G. Sp;
SP.

Family: CYMBELLACEAE
Phaeodactylum Bohlin
P. tricornutum Bohlin
SP, S, A.
Amphora Ehrenberg
S.
A. spectabilis Gregory
A. coffeaeformis (Agardh) Kützing;
SP.
A. ovalis Kutzing;
SP, S, A.

Family: EPITHEMIACEAE
Epithemia de Brebisson
E. Kurgida (Ehrenberg) Kutzing;
SP, A.

Family: BACILLARIACEAE
Bacillaria Gmelin
B. paxillifer (O.F. Muller) Hendey;
SP, S, O.
Nitzschia Hassall
N. apiculata (Gregory) Grunow;
SP, S, A.
N. dubia Wm. Smith;
SP, S.
N. closterium (Ehrenberg) Wm. Smith;
SP, S, N.
N. filiformis Wm. Smith;
SP, A.

Sub-order: SURIRELLINEAE
Family: SURIRELLACEAE
Surirella Turpin
S. ovata Kutzing;
SP.

Kützing) Wm. Smith;
SP, S.
S. gemma (Ehrenberg) Kützing;
SP, S, A, O.

Class: DINOPHYCEAE
Order: PROROCENTRALES
Family: PROROCENTACEAE
Exuviaella Cienkowski
E. Sp.;
SP, S, A, sD.
Prorocentrum Ehrenberg
P. micans Ehrenberg
SP, S, A, sD.
Order: DINOPHYSIALES
Family: DINOPHYSIACEAE
Dinophysis Ehrenberg
D. Sp.;
SP, S, A, sD.
Order: GYMNODINIALES
Family: GYMNODINIACEAE
Gymnodinium Stein
G. Sp.;
SP, S, D.
Family: NOCTILUCACEAE
Noctiluca Suriray in Lamarck
N scintillans (Macartney) Ehrenberg;
SP, S, N, D.
Family: PERIDINIACEAE
Peridinium Ehrenberg
P. ovatum (Pouchet) Schütt;
SP, S, A, L, sD.
Family: GONYAULACACEAE
Gonyaulax Diesing
G. Sp.;
SP, S, A, sD.

Class: HAPTOPHYCEAE
Order: PRYMNESIALES
Family: PHAEOCYSTACEAE
Phaeocystis Lagerheim
P. pouchetti (Hariot) Lagerheim;
SP, S, D.
Order: PRASINOPHYCEAE
Family: HALOSPHAERACEAE
Halosphaera Schmitz
H. viridis Schm.;
SP.
Family: CERATIACEAE
Ceratium Schrank
C. furca (Ehrenberg) Clap. et Lachm.;
SP, S, D.
C. fusus (Ehrenberg) Dujard;
SP, S, sD.
C. macroceros (Ehrenberg) Vanhoffen;
SP, A, D.
C. tripos (O.F. Mull) Nitzsch.;
SP, S, A, sD.
C. longipes (Bailey) Gran;
A.

Legend:

Y = all seasons
SP = spring
S = summer
A = autumn
W = winter
N = neritic
B = boreal
Ar = arctic
L = littoral
O = oceanic
U = ubiquitous
T = tychopelagic
D = dominant
sD = sub-dominant

Table VI List of Phytoplankton common to station (G), Greenfield, Clwyd, U.K. and other coastal sea waters.

Species reported in this paper	Species reported in previous work now found at Greenfield Reference Numbers (see below)												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Melosira nummuloides Agardh		x	x										
M. juergensii Agardh				x									
Paralia sulcata (Ehrenberg) Cleve	x			x	x			x		x			
Cyclotella striata (Kutzing) Grunow													
Coscinodiscus radiatus Ehrenberg	x	x	x	x	x								
Coscinodiscus lineatus Ehrenberg		x	x	x									
C. concinnus Wm. Smith				x						x			
C. grani Gough	x			x									
C. eccentricus Ehrenberg	x	x	x	x	x								
Thalassiosira nordenskioldii Cleve				x				x					x
T. gravida Cleve				x				x		x			
T. decipiens (Grunow ex Van Heurck) Jorgensen				x				x					
Podosira stelliger (Bailey) Mann	x		x		x								
Skeletonema costatum (Greville) Cleve					x			x					
Stephanopyxis turris (Greville) Ralfs in Pritchard					x								
Actinoptychus senarius (Ehrenberg)			x	x									
Biddulphia aurita (Lyngbye) Brebisson		x	x		x			x					
B. rhombus (Ehrenberg) forma rhombus		x	x		x			x					
B. regia (M. Schultze) Ostenfeld	x		x	x	x			x		x			
B. mobiliensis (Bailey) Grunow ex Van Heurck	x			x	x								
B. sinensis Greville				x	x			x	x	x		x	
B. Laevis Ehrenberg			x										
Eucampia zodiacus Ehrenberg				x	x		x	x		x			
Triceratium favus Ehrenberg			x										
Ditylum brightwelli (T. West) Grunow ex Van Heurck		x			x	x			x		x		
Bellerochea malleus Van Heurck forma malleus					x			x		x			
Chaetoceros densum Cleve				x									
C. danicum Cleve				x									

C. decipiens Cleve				x	x				x			
C. laciniosum Schütt				x								
C. debile Cleve				x			x					
Bacteriastrum hyalinum Lauder								x				
Leptocylindrus danicus Cleve	x			x	x		x	x				
L. minimus Gran							x	x				
Guinardia flaccida (Castracane) Peragallo	x			x	x			x	x			
Lauderia borealis Gran	x			x	x							
Rhizosolenia alata Brightwell forma alata				x			x	x	x			
R. delicatula Cleve	x			x	x		x	x				
R. stolterfothii H. Peragallo	x			x	x		x	x	x			
R. robusta Norman ex Pritchard				x				x				
R. shrubsolei Cleve	x	x		x				x			x	x
R. setigera Brightwell				x	x			x				
R. styliformis Brightwell				x				x	x		x	
Fragilaria oceanica Cleve		x			x							
F. crotonensis (A.M. Edwards) Kitton					x							
Asterionella japonica Cleve & Müller ex Gran				x	x			x	x		x	
Synedra affinis Kutzing		x										
S. tabulata (Agardh) Kutzing	x											
Thalassionema nitzschioides Hustedt	x			x			x					
Grammatophora marina (Lyngbye) Kutzing		x										
Achnanthes brevipes Agardh		x	x	x								
Cocconeis scutellum Ehrenberg var. Scutellum		x		x								
C. placentula Ehr.		x										
Navicula crucigera (Wm. Smith) Cleve		x										
N. digito-radiata (Gregory) Ralfs in Pritchard			x									
N. lyra Ehrenberg		x	x									
N. cryptocephala Kutzing					x							
Diploneis didyma (Ehrenberg) Cleve			x									
Pleurosigma angulatum (Quekett) Wm. Smith		x	x	x								
Gyrosigma balticum (Ehrenberg) Cleve		x										
G. fasciola (Ehrenberg) Cleve				x								
Amphiprora paludosa Wm. Smith			x									

Phaeodactylum tricornutum Bohlin					x								
Amphora coffeaeformis (Agardh) Kützing		x											
Bacillaria paxillifer (O.F. Müller) Hendey	x			x	x								
Nitzschia closterium (Ehrenberg) Wm. Smith		x		x	x		x	x					
Surirella ovata Kützing		x											
S. gemma (Ehrenberg) Kützing		x	x	x	x								
Prorocentrum micans Ehrenberg				x		x	x						
Noctiluca scintillans (Macartney) Ehrenberg				x	x								
Ceratium furca (Ehrenberg) Calp. et Lachm.				x	x	x							
Ceratium fusus (Ehrenberg) Dujard	x			x	x	x	x				x	x	x
C. macroceros (Ehrenberg) Vanhoffen				x	x	x						x	
C. tripos (O.F. Mull.) Nitzsch.				x		x						x	x
C. longipes (Bailey) Gran				x	x	x							x
Phaeocystis pouchetti (Hariot) Lagerheim	x			x	x								
Halosphaera viridis Schm.						x							

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Table VII Welsh Dee Estuary: List of Algal Species Found on Mud Samples at Station (G) Greenfield, Clwyd, U.K.

Species Name	Dates of Collection 16/4	10/5	7/6	24/	23/8	23/9
Melosira nummuloides	P	P	A	A	P	P
M. juergensii	A	A	P	A	A	A
Paralia sulcata	P	P	A	P	A	P
Cyclotella striata	P	P	P	A	P	A
C. Sp.	A	A	A	P	A	A
Skeletonema costatum	P	A	A	P	P	A
Fragilaria pinnata	P	A	A	A	P	P
F. oceanica	A	A	A	P	P	P
F. hyalina	A	A	P	A	A	P
F. crotonensis	P	A	P	P	A	P
Raphoneis surirella	A	A	A	P	P	A
Synedra tabulata	A	A	A	P	A	A
S. pulchella	P	P	P	A	P	P
S. undulata	A	A	P	P	A	A
Licmophora gracilis	A	A	P	A	P	P
Grammatophora marina	A	A	A	P	A	P
Achnanthes brevipes	P	P	P	A	P	P
Cocconeis scutellum	A	P	P	A	P	P
C. placentula	P	P	A	P	A	A
Navicula crucigifera	P	A	A	A	A	A
N. salinarum	P	P	A	A	P	A
N. digito-radiata	A	P	A	P	P	A
N. viridula	P	A	P	P	A	A
N. lyra	A	A	P	A	A	A
N. cincta	A	A	P	A	A	A
N. cryptocephala	P	A	A	A	A	P
Diploneis elliptica	A	A	P	A	A	P
D. didyma	A	P	A	P	A	A
D. bombus	P	A	A	A	A	A
Pinnularia Sp.	A	P	P	A	P	A
Pleurosigma normanii	A	A	A	P	A	A
P. aestuarii	P	P	P	A	P	A
P. angulatum	P	A	A	A	A	P
Gyrosigma wansbeckii	P	A	P	A	A	P
G. balticum	A	P	A	P	P	A
Gomphonema Sp.	A	P	P	A	A	P
Phaeodactylum tricornutum	A	A	P	A	A	P
Amphora spectabilis	A	P	P	A	A	P
A. ovalis	P	A	A	P	A	A
Bacillaria paxillifer	A	A	P	A	A	P
Nitzschia apiculata	A	A	A	P	A	P
N. dubia	A	P	P	A	A	A
N. closterium	P	A	P	P	P	A
N. filiformis	P	A	A	A	A	P
Surirella ovata	P	A	A	P	A	A
S. gemma	A	P	A	P	P	P

P = Found; A = Not found.

Table VIII Correlation coefficients between phytoplankton pigments and chemical parameters in Welsh Dee Estuary, U.K.

		Spring		Summer
Parameters	Log Phytoplankton No.	Tidal Height	Chloro-phyll-a	Chloro-phyll-a
Silicate	-.561	-	-	-
Fe (T)	-.658	- .725	-.822	-
Zn (T)	-.511	-	-	-
Tidal Ht.	.867	-	-	-
Plankton No.	.647	-	.909	-
S (0/00)	-	.657	.669	.579
Chlorophyll-a	-	.733	-	-
B.O.D.	-	-	- 0.536	-

in the waters of the British Isles (Table VI*) can be found in the supplementary materials published on magnetic disc.

The dominant algal species in the waters of Dee Estuary that were collected were *Paralia sulcata, Coscinodiscus radiatus, C. marginatus, Actinocyclus octonarius* var. *octonarius, Thalassiosira nordenskioldii, Podosira stelligera, Bellerochea malleus, Skeletonema costatum, Biddulphia aurita, Rhizosolenia styliformis, Chaetoceros danicum, C. densum, Asterionella japonica, Noctiluca scintillans, Ceratium macroceros, Peridinium ovatum* and *Phaeocystis pouchetti.* A list of the plankton collected from the sea floor on six occasions between April and September are given in Table VII* in the supplementary materials.

Seasonal succession of phytoplankton associations based upon their presence or absence during different seasons showed that of the 34 species representing spring, summer and autumn *Coscinodiscus marginatus, Thalassiosira condensata, Podosira stelliger, Skeletonema costatum, Eucampia zodiacus, Bellerochea malleus, Chaetoceros densum, C. decipiens, Prorocentrum micans, Peridinium ovatum, Dinophysis* sp., and *Ceratium tripos* were the most common forms. *Rhizosolenia setigera, R. styliformis, R. stolterfothii, Asterionella japonica, Gymnodinium* sp., *Noctiluca scintillans, Ceratium furca, C. fusus, Phaeocystis pouchetti, Paralia sulcata, Coscinodiscus radiatus, C. eccentricus, Actinocyclus octonarius* var. *octonarius, Thalassiosira nordenskoldii, Hyalodiscus scoticus, Biddulphia aurita, Chaetoceros debile, C danicum* were the most common of the 42 species which occurred in spring and summer seasons. Out of the nine species of summer and autumn *Stephanodiscus rotula* and *Ceratium macroceros* were the most common algae. *Rhizosolenia alata* and *Coscinodiscus lineatus* were the dominant species of summer while *Coscinodiscus concinnus* and *Thalassionema nitzschioides* were commonly observed in spring. A correlation of the seasonal phytoplankton pigments and chemical parameters is given in Table VIII.

Biomass. During the period of study the chlorophyll-a concentration in the water varied from 0.38 $\mu g\ L^{-1}$ at 1900 h on April 9 to 5.41 $\mu g\ L^{-1}$ at 1000 h on July 18 and 5.21 $\mu g\ L^{-1}$ at 1015 h on August 15. In general higher concentrations were observed in the morning hours. The average concentration of this pigment on each of the eight sampling days lay in the range 1.63-3.71 $mg\ L^{-1}$, the highest value being in May and the lowest in September (Table II), revealing high phytoplankton production in summer. Regression analyses between chlorophyll-α and other measured parameters of the water (Table I) revealed positive correlations (Table III) between the pigment and

salinity, dissolved oxygen and plankton cell numbers.

Species diversity and variation. The species diversity (d), (Parsons and Takahashi, 1973), of the Dee estuary phytoplankton varied from 2.33 to 3.99 (Table II) during the period of study.

The d values obtained are characteristic of oceanic plankton where d generally varies from 3.5 to 4.5 (Margalef, 1967).

Discussion

The Dee Estuary waters showed lower values of pH, silicate, nitrogen, orthophosphate, iron and manganese than the average values for the River Dee at Queensferry for the year 1966 - 1971 and 1970 - 1971 (O'Sullivan, 1975). The concentrations of silica, phosphate and ammonia nitrogen were higher than those of Liverpool Bay waters (Burrows and Sharples, 1973). The physico-chemical parameters at Greenfield thus lie between the values obtained for waters of Queensferry and Liverpool Bay. The phosphate and silicate values were also lower than those for Morecombe and Cardigan Bays, the Cumberland Coast and the North East Irish Sea (Jones and Folkard, 1971). Queensferry waters were influenced by the Dee river and polluted water discharges, while Liverpool Bay was principally oceanic in character.

The sludge that enters Liverpool Bay contains Fe, Zn, Cu, Mn, Pb, Cr, Ni, Cd, Hg, Phosphate, anionic detergents and chlorinated hydrocarbons (W.P. Report, 1973). The bio-assay of sea water by Burrows and Sharples (1973) indicated that *Laminaria saccharina* was more sensitive to copper than either *Phaeocystis* or *Skeletonema.* The toxic action of copper and zinc, when they occur together, is the same as that of copper and the toxic action of sludge is controlled by copper concentration (Burrows and Sharples, 1973). The indirect correlation was obtained between iron, silica, zinc and log phytoplankton numbers during the spring season which involved the trace metal utilization by the phytoplankton. There appeared to be no toxic effects on the populations of the phytoplankton.

Previous work (Spencer, 1972) revealed patchy distribution of phytoplankton in the surface waters of Liverpool Bay in 1970 but the chlorophyll concentration in the Dee estuary appears to be greater than in Liverpool Bay or in the Irish Sea between Wicklow and Dublin (Sykes and Boney, 1970). The phytoplankton is regarded as stable when d values are about 2.5 and in active growth when d lies in the range 3.5-4.0 (Margalef, 1967). If the water turbulence is strong as it is in the Dee estuary, the diversity in small volumes may be great and it will only stabilize when large volumes of water are examined (Margalef, 1967). In the work reported here where relatively small water samples were collected, such turbulence may be resulted in high diversity values and the observed inverse correlation between chlorophyll concentration and d values. An indirect correlation was obtained between iron, silica and zinc with log phytoplankton numbers during the spring, when probably involved trace element utilization by the phytoplankton. We conclude that in these waters there were little toxic effects on the phytoplankton population.

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OVINE ILL-THRIFT IN NOVA SCOTIA. 13. ANOREXIA AND DIGESTIBILITY DECLINE IN FEMALE LAMBS GIVEN 3,7,11-$^3H_3$-3-ACETOXY-7,15-DIHYDROXY-12, 3-EPOXYTRICHOTHEC-9-EN-8-ONE*

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3,7,11-$^3H_3$-3-Acetoxy-7,15-dihydroxy-12,13-epoxytrichothec-9-en-8-one (I, R=H, R'=Ac) was produced by *Fusarium culmorum* (CMI 14764) grown on a defined medium supplemented with 5-$^3H_2$-mevalonic acid. The metabolite was rigorously purified and the position of the 3-^3H label unequivocally determined by tritylation of the 15-hydroxy group, hydrolysis of the ester and regiospecific oxidation of the 3-hydroxy group thus generated. The metabolite (**I**, R=H, R'=Ac) given as a single intraruminal dose (5 mg kg^{-1}) to female lambs resulted in a 44% decline in food intake and a 5% decrease in apparent digestibility of this feed, in the 4 days following administration of the toxin (**I**, R=H, R'=Ac).

Introduction

Deoxynivalenol (= vomitoxin = Rd toxin = 3,7,15-trihydroxy-12,13-epoxytrichothec-9-en-8-one = **I**, R=R'=H, Yoshizawa and Morooka, 1973) was shown to be an emetic when present in the diet of pigs (Vesonder et al., 1973) and subsequently proved to induce anorexia in mice (Pestka et al., 1986), swine (Friend et al., 1986, Prelusky, 1994) and sheep (Harvey et al., 1986). It is produced in culture by *Fusarium culmorum* and *F. graminearum* (Greenhalgh et al., 1984, 1986b) where it is invariably accompanied by a large number of congeners and indeed may well be an artifact of the isolation procedures since the esters (**I**, R=H, R'=Ac; **I**, R=Ac, R'=H) are very readily hydrolysed in mildly alkaline solution (Grove et al., 1988) or by intracellular enzymes (Yoshizawa and Morooka, 1975, Yoshizawa and Luangpitsuka, 1985). Thus there is some agreement that the alcohol (**I**, R=R'=H) is not normally present in plant tissues but rather occurs as the 3- or 15-acetate. It is possible that the pharmacology and hence toxicity of these esters differ from their parent alcohol and a few reports have appeared of anorexia in mice (Pestka et al., 1986) and emesis in pigs (Pestka et al., 1987) after treatment with 15-acetyl-deoxynivalenol (**I**, R=Ac, R'=H).

Fusarium graminearum has not been isolated from soils at Nappan, Nova Scotia, and *F. culmorum* has been found in only one root culture from many hundreds of soil samples collected from upland pastures at that Experimental Farm (Brewer et al., 1971; Brewer and Taylor 1980).

* Brewer et al., 1990 is regarded as Part 12.

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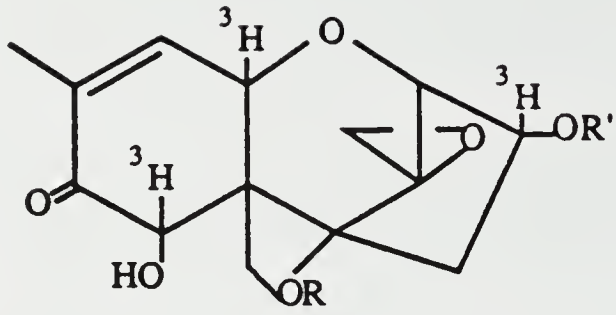

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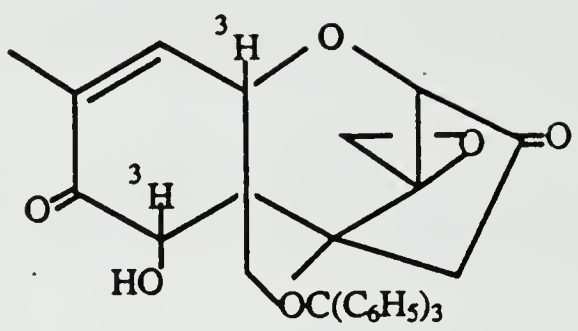

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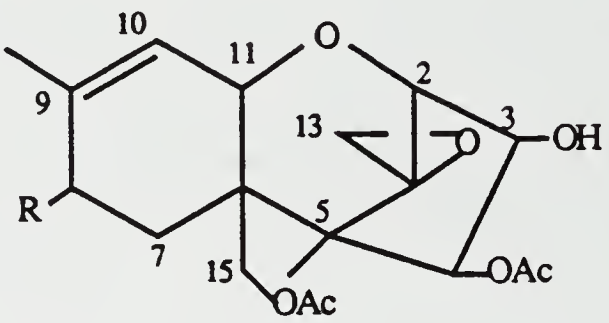

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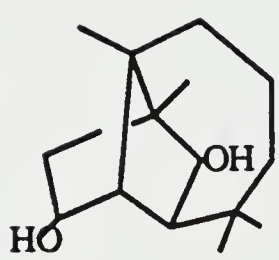

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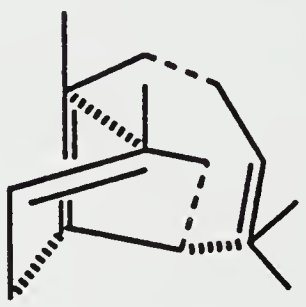

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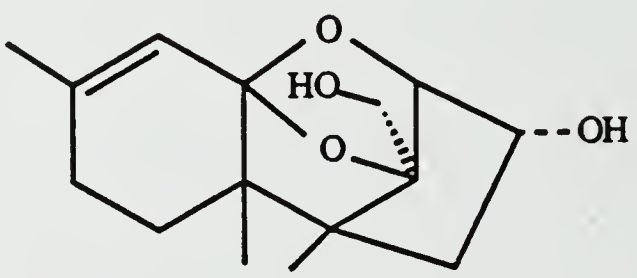

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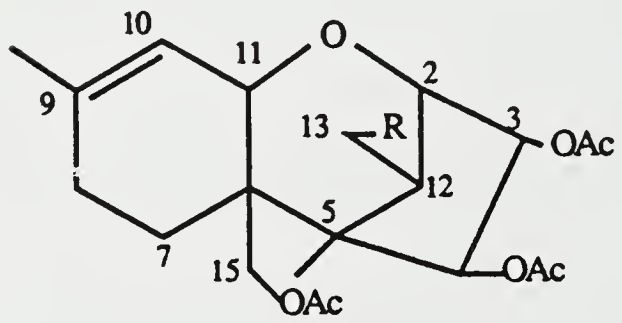
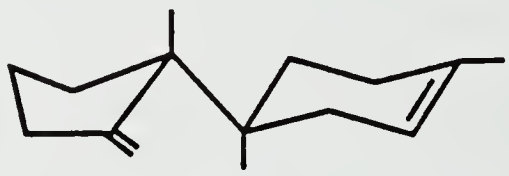


VI



However *F. solani* is commonly found in these soil samples. For example in 1973, 71 isolates were obtained of mean frequency $2x10^4$ (number of propagules g^{-1} dry soil), from 197 soil samples. *F. solani* is known to produce the trichothecenes (Ishii et al., 1971), neosolaniol (**II**, R=OH), diacetoxyscirpenol (**II**, R=H) and T2 toxin (**II**, R=$OCOCH_2CHMe_2$) - the oral toxicity of the latter in sheep is about an order of magnitude greater than deoxynivalenol (Rukhlyada, 1983). These considerations suggested a careful examination of the effect of 3-acetyldeoxynivalenol, of known purity, on the dietary intake and digestion of female lambs. The results of such experiments are reported in this paper.

Materials and Methods

General Full details of thin layer chromatography, solvents used, and methods of detection have been reported in a preceding publication (Grove et al., 1988). Infrared spectra were obtained on samples dispersed in potassium bromide using a Perkin-Elmer 283B spectrometer, and ultraviolet spectra on solutions in methyl alcohol using a Cary 14 instrument. Optical rotations (± = standard deviation) were measured using a Rudolf polarimeter. A Beckman 7500 scintillation counter was used to determine the radioactivity of samples; quenching factors were calculated by the channel ratio method and the algorithm used was written to accommodate the radioactive decay of tritium. All serum, urine and ultracentrifuged rumen fluid samples (1 mL; Brewer et al., 1990) were added to a solution (15 mL) of 2,5-diphenyloxazole (60 mg), 1,4-bis(5-phenyloxazol-2-yl)benzene (3.8 mg), naphthalene (0.9 g), ethylene glycol (0.3 mL), methyl alcohol (1.8 mL) and 1,4-dioxane. All such solutions were kept at room temperature for 24 h before measurement of their radioactivity. Samples of 3-acetyldeoxynivalenol (**I**, R=H, R'=Ac) and its derivatives were added to a solution (15 mL) of 2,5-diphenyloxazole (75 mg) in toluene for determination of their radioactivity. The radioactivity of the 5-$^3H_2$-mevalonic acid (New England Nuclear) was checked using the scintillation fluid used for the serum samples.

Animal husbandry and digestibility studies The husbandry of the experimental sheep (mean body weight 27.9±3.7 kg) was as described in an earlier paper (Brewer et al., 1990). The sheep pens were fitted with trays mounted on rails beneath their wooden slatted floors. These trays were dressed with coarse polyester filter cloth (Brewer et al., 1982) which retained faecal pellets and allowed urine to pass into bottles of capacity 2L. Each morning at 0600 h the trays were removed, the faeces collected and weighed and the volume of urine was measured. The filter cloth was washed, the trays reassembled and replaced under the pens. Weighed samples of urine and faeces were lyophilized to determine their dry weights. At the same time all residual feed was collected, weighed and replaced with a weighed quantity of fresh feed. Details of these dry weights are given in Tables I* and II* in the version of this paper on magnetic disc. The *in vivo* digestibility was then calculated in the usual way ((Feed consumed (g)-(faeces (g)+urine (g) excreted))x100)/Feed consumed (g). Random samples of the feed were dried in a vacuum oven at 60°; its *in vitro* digestibility was measured as described by Brewer et al., (1986). The method of collecting rumen samples has been reported (Brewer et al., 1990) and blood samples were collected by jugular venepuncture into heparinized evacuated tubes.

Formulation of 3-acetyldeoxynivalenol for administration to sheep 3-Acetyldeoxynivalenol (=A, 278.5 mg; defined below) was dissolved in potable (Nova Scotia Liquor Commission) ethyl alcohol-water (19:1, 25 mL) and the solution diluted with water (20 mL). This solution (22 mL, = 5 mg kg^{-1}) was administered intraruminally to one animal and 23 mL to the other. The duodenal tube used for the second animal was washed with ethyl alcohol (5 mL), the solution evaporated and the radioactivity of the residue (0.91 mg; = 5 mg kg^{-1} net dose) determined. The control animals were dosed similarly with ethyl alcohol-water (3:4, 25 mL).

Preparation of 3,7,11-$^3H_3$-3-acetoxy-7,15-dihydroxy-12,13-epoxythricothec-9-en-8-one An inoculum (1 L) of *Fusarium culmorum* (CMI 14764) was prepared as described (Greenhalgh et al., 1984) and added to sterile production medium (10 L) consisting of sucrose (400 g), glycerol (100 g), sodium chloride (50 g), potassium dihydrogen phosphate (35 g), diammonium hydrogen phosphate (10 g), magnesium sulfate heptahydrate (2 g) and water (Brewer et al., 1982). The culture was treated with

sterile rape-seed oil, was stirred at 300 r min^{-1} at 28° and aerated (6 L min^{-1}). After 4 days growth, 5-$^3H_2$-mevalonic acid (5 μCi, 2 mg) in water (5 mL) was added and the culture was harvested and extracted 4 days later (Greenhalgh et al., 1984). The crude methyl alcohol solution obtained by this method, was evaporated, the residue dissolved in toluene (50 mL) and the solution evaporated. The resulting gum (4.49 g) was dissolved in chloroform (10 mL) and applied to a silica gel column similar to that described (Greenhalgh et al., 1984) except that the chromatogram was developed at 25° and the column was eluted as follows: chloroform-ethyl alcohol (199:1, 750 mL); chloroform-methyl alcohol (79:1, 600 mL): chloroform-methyl alcohol (39:1, 3.8 L); chloroform-methyl alcohol (4:1, 1 L) and methyl alcohol (1 L). After recycling the first 400 mL of eluate the following fractions were collected (volume of each in parenthesis): 1-3 (500 mL); 4 (250 mL); 5-14 (50 mL); 15-34 (25 mL); 35-44 (50 mL); 45-52 (100 mL); 53 (200 mL); and 54-58 (500 mL). The residues from fractions 41-46 inclusive (1.4 g) were recrystallized from diethyl ether-petroleum ether (5:1) to give colorless needles, 0.5436 g, m. p. 180-185°, 4.76 x 10^5 d min^{-1} $mmol^{-1}$. This material (150 mg) recrystallized from diethyl ether gave needles m. p. 184-185°, 4.97 x 10^5 d min^{-1} $mmol^{-1}$, and one further recrystallization from diethyl ether provided flat colorless blades, m. p. 185°, 4.98 x 10^5 d min^{-1} $mmol^{-1}$, λ_{max}. 220 nm (ε 6000), $[\alpha]^{24}_D$ +34.5±0.2°. This material (113 mg) was taken up in ethyl alcohol (2 mL) and hexane (1 mL) added. The solution was concentrated to 2 mL, hexane (1 mL) added, the solution allowed to evaporate to about 1.5 mL and then kept at -15° overnight. The supernatant mother liquors were decanted at -15° and the crystals (68 mg, m. p. 185°, 4.99 x 10^5 d min^{-1} $mmol^{-1}$, = A) washed with ethyl alcohol-hexane (1:1, 3 x 1 mL) at this temperature. The combined washings and mother liquors were evaporated giving a colorless solid (45 mg, m. p. 185°, 4.98 x 10^5 d min^{-1} $mmol^{-1}$). The 15-1'-naphthylurethane (m. p. 80-82°; $[\alpha]^{24}_D$ +52.5° (c, 1.13 $CHCl_3$); Found: C, 66.4; H, 6.07; N, 2.85. $C_{28}H_{29}NO_8$ requires C, 66.3: H, 5.76; N, 2.8%; 4.95 x 10^5 d min^{-1} $mmol^{-1}$; δ_H 1.15 ($3H_{14}$); 1.84 ($3H_{16}$); 2.12 (3H); 2.02-2.38 ($2H_4$, m); 3.11 ($H_{13\alpha}$); 3.17 ($H_{13\beta}$, *J* 3 Hz); 3.85 (H, e); 3.90 (H_2, *J* 3 Hz); 4.38 ($H_{15\alpha}$, *J* 12 Hz), 4.55 ($H_{15\beta}$); 4.81 (H_{11}); 4.85 (H_7); 5.22 (H_3), 6.59 (H_{10}); 6.75 (H_{NH}, e); 7.43-7.88 (7H, aromatic)) was prepared as described by Grove et al., (1988) for the phenylurethane derivative.

Isolation and radioactivity of other sesquiterpene metabolites Fractions 49-52 from the chromatogram described in the preceding paragraph did not absorb ultraviolet light but did react with the ceric sulfate-sulfuric acid reagent (Grove et al., 1988). The fractions were combined (0.63 g) and rechromatographed on a silica gel column (20 x 7.5 cm) which was developed with chloroform-methyl alcohol (79:1, 4 L) and then with chloroform-methyl alcohol (39:1) when fractions (100 mL) were collected. Thin layer chromatography of the fractions showed that fractions 1-3 inclusive contained 3-acetyldeoxynivalenol (**I**, R=H, R'=Ac, 71 mg). Fractions 4-7 inclusive were combined (0.5 g), taken up in tetrahydropyran (5 mL) and hot cyclohexane (2 mL) added. The colorless solution on standing at 4° for 18 h gave culmorin (**III**, Ashley et al., 1937) which was recrystallized from the same solvent giving colorless plates, m. p. 183°, $[\alpha]^{24}_D$ -15.6±0.8° (c, 0.623 MeOH), Found: C,75.4; H, 11.05; O, 12.8; m/z 238.1922. Calculated for $C_{15}H_{26}O_2$ C, 75.6; H, 11.0; O, 13.4% m/z 238.1933; 3.31 x 10^6 d min^{-1} $mmol^{-1}$.

The residues from fractions 54 and 55 from the original chromatogram were crystalline and did not absorb in the ultraviolet, they were combined (0.2 g) and recrystallized from ethyl acetate giving needles (0.17 g) m. p. 224°, 4.12 x 10^5 d min^{-1} $mmol^{-1}$ = sambucinol (**IV**, Mohr et al., 1984). The ^1H n.m.r. and X-ray crystallography of this material have been reported (Greenhalgh et al., 1986a).

7,11-$^3H_2$-12,13-epoxy-7a-hydroxy-15-trityloxytrichothec-9-en-3,8-dione (**Ia**) - A solution (10 mL) of 3,7,11-$^3H_3$-3α,7α-dihydroxy-12,13-epoxy-15-trityloxytrichothec-9-en-8-one (Grove et al., 1988, **I**, R=$(C_6H_5)_3C$, R'=H, 43.9 mg, 4.92 x 10^5 d min^{-1} $mmol^{-1}$) in dry benzene was treated with pyridinium chlorochromate on alumina (Cheng et al., 1980, 250 mg, 0.2 mmol Cr). The mixture was stirred at room temperature for 5 h when it was filtered and the alumina washed thoroughly with diethyl ether. The filtrate and washings were evaporated and the residue (39.5 mg) applied to a silica gel plate (Merck, $60F_{254}$, 20x20x0.05 cm). The chromatogram was developed with diethyl ether-hexane (3:1) and four bands were then visible under reflected ultraviolet light. The most polar band gave the starting alcohol (2.3 mg) on elution from the silica. The main band was eluted with ethyl acetate, the eluate evaporated and the residue (37.2 mg) in diethyl ether (2 mL) on treatment with hexane gave a solid (13.5 mg, m. p. 80-85°) as a film. This solid was taken up in *t*-butyl alcohol (5 mL) and the solution lyophilized giving crystals of 7,11-$^3H_2$-12,13-epoxy-7α-hydroxy-15-trityloxytrichothec-9-en-3,8-dione (**Ia**), m. p. 70°, $[\alpha]^{20}_D$ -49.2° (c 2.15 $CHCl_3$), ν_{max}. 3460, 1767, 1685 cm^{-1}, 3.29 x 10^5 d min^{-1} $mmol^{-1}$; Found: C, 74.6; H, 6.6; O, 18.3. $C_{34}H_{32}O_6.C_4H_{10}O$ requires C, 74.7; H, 6.9; O, 18.3%, δ_H (resonances of C_4H_9OH omitted) 1.01 ($3H_{14}$), 1.80 ($3H_{16}$), 2.21 ($H_{4\beta}$, $^2J_{HH}$ 19.44 Hz), 3.13 ($H_{15\alpha}$ *J* 10.7 Hz), 3.49 ($H_{15\beta}$), 3.17 (H_{13}, *J* 4.2 Hz), 3.27 (H_{13}), 3.30 ($H_{4\alpha}$), 3.50 (H_2), 3.56 (H, e), 4.73 (H_{11} *J* 5.96Hz), 4.86 (H_7, e), 6.47 H_{10} $^3J_{H10H11}$ 1.5 Hz), 7.16-7.39 (15H).

Results

3,7,11-$^3H_3$-3-Acetyldeoxynivalenol (**I**, R=H, R'=Ac) was purified to constant elemental analysis, optical rotation, melting point and specific molar radioactivity. It eluted from a reverse phase partition chromatography column (Synge and White, 1960) as a Gaussian distribution without detectable distortion. It was converted through the steps: **I**, R=H, R'=Ac → **I**, R=$(C_6H_5)_3C$, R'=Ac → **I**, R=$(C_6H_5)_3C$, R'=OH in 84% overall yield and the sequential products of these two reactions had the same specific molar radioactivity and the same level of purity as the metabolite. Regiospecific oxidation (Grove, 1994) of the alcohol (**I**, R=$(C_6H_5)_3C$, R'=OH) gave the ketone (**Ia**) in 87% yield (or 73% overall from 3-acetyldeoxynivalenol) whose specific molar radioactivity was, as expected (Arigoni et al., 1973, Cane and Ha, 1988), two thirds of its parent alcohol (**I**, R=$(C_6H_5)_3C$, R'=OH).

The 3,7,11-$^3H_3$-3-acetyldeoxynivalenol purified as described in the preceding paragraphs, administered directly into the rumen of two female lambs was rapidly hydrolysed to deoxynivalenol (**I**, R=R'=H). Chromatography (Grove et al., 1988) of rumen fluid collected and ultracentrifuged 5 min after administration of the toxin and then kept at -78° for 6 h, indicated the presence of 3-acetyldexoynivalenol and deoxynivalenol in the ratio 1:1.

The decline in radioactivity in rumen fluid in both dosed animals was exponential and fitted the equation: $x=983.896.e^{-0.0879y}$ with an index of fit (r^2) of 0.918, where y=concentration (mg mL^{-1}) of 3-acetyldeoxynivalenol from the measured radioactivity and x=time in minutes. Assuming a rumen volume of 2 L, and therefore an initial concentration (~70 mg mL^{-1}) of 3-acetyldeoxynivalenol, an apparent half life of deoxynivalenol in the rumen of these sheep can be calculated from this equation as 46 min. The radioactivity of the serum of these sheep was a maximum 300-400 min after dosing and, as reported by Prelusky et al., (1985) was apparently biphasic. Twenty three percent of the radioactivity was excreted in the urine.

The mean feed (*in vitro* digestibility 58.4%) consumption of the control animals over the 12 day experimental period (26 Aug - 6 Sept) was 1626±150 g day^{-1}, and the mean feed consumption of the dosed animals in the 4 days prior to dosing (26 Aug - 29 Aug) was 1678±269 g day^{-1}. By contrast the mean feed consumed by the dosed animals in the 5 days after dosing was 983±124 g day^{-1} and the feed consumed by the control animals in this period was 1670±167 g day^{-1}. The difference between these means (687 g) or between the statistics given above (1626g & 1678 g) is obviously real and agrees with results reported by other workers (Harvey et al., 1986). Six days after dosing the feed intake of the dosed animals returned to normal e.g. their mean daily consumption from September 4 to September 6 inclusive was 1495 g.

The calculated digestibility of the feed consumed by the control animals and that consumed by the dosed animals prior to administration of the toxin, taking the mean value of the dry weight of feed consumed and the dry weight of faeces and urine excreted was about 54%. The mean digestibility calculated in the same way for the dosed animals between 30 August and September 2 was 48.7%. During the same time period a calculation of the digestibility of the same feed in the case of the control animals gave the result 52%. On a daily basis the calculated digestibilities of the feed on the day of dosing (=30 August) and for the next 3 days were 37%, 44%, 51% and 61% while the corresponding figures for the control animals were 51%, 56%, 54%, and 46%.

Discussion

It is widely believed that the acetates of deoxynivalenol (**I**, R=R'=H) are the major metabolites produced by *Fusarium culmorum*, but this is not the case, as was clearly illustrated by the isolation of culmorin by Raistrick and his co-workers (Ashley et al., 1937) almost 60 years ago. In the present work culmorin, sambucinol and 3-acetyldeoxynivalenol were isolated in the ratio 3:1:7. Their separation is not simple and crystalline samples of each are often contaminated with the others. Such contamination is difficult to detect using for example, high pressure reverse phase partition chromatography because only the trichothecene absorbs ultraviolet light. These facts are toxicologically significant because the sesquiterpene 3,4,15-triacetoxy-12-hydroxytrichothec-9-ene (**V**, R=OH) is 200 times less toxic than 3,4,15-triacetoxy-12,13-epoxytrochothec-9-ene (**V**, R=O-C_{12}; Grove and Mortimer, 1969). It may be concluded that culmorin and/or sambucinol admixed with deoxynivalenol or its esters will appear to reduce the toxicity of the latter.

By the analytical methods at our disposal the ^{3}H-3-acetyl-deoxynivalenol dosed to our experimental sheep was not contaminated by culmorin, sambucinol or any of the other 11 or 12 known metabolites of *F. culmorum* (Greenhalgh et al., 1986a; Zamir et al., 1990, 1992). The sheep after dosing differed from the control animals only in that they appeared to be somewhat lethargic, but their decreased food consumption was very obvious as was their gradual return to normality. This single dose did not affect their weight gain and the following season all four experimental animals produced healthy lambs. The anorexia observed in the dosed sheep is a well documented phenomenon for the effect of low doses of trichothecenes to mammals but so far as we are aware, a concomitant decline in digestibility of fodder by ruminants has not been reported. Although *F. culmorum* is not a common species in the fungal flora of pasture soil at Nappan (Brewer and Taylor, 1980) other *Fusarium* species are. In the seasons 1973-1975 inclusive, 272 isolates of *Fusarium* spp. were isolated from 504 soil

samples collected. A random sample of 11 of these 272 isolates revealed that 8 (73%) of them produced toxic metabolites (Brewer and Taylor, unpublished work). It suggests that these Fusaria, *a priori*, are a parameter in the ill-thrift of lambs on pasture at Nappan.

The radioactivity data given in the Experimental section, indicate that the specific molar radioactivity of sambucinol is less than that of 3-acetyldeoxynivalenol, thus confirming the suggestion of Zamir et al., (1990) and the more recent molecular biology of Hohn et al., (1995) that there are different pathways to these two metabolites from trichodiene (**VI**). However the specific molar radioactivity of culmorin was about 7 times that of 3-acetyl- deoxynivalenol and 8 times that of sambucinol. Biosynthetically this might be expected for its formation from mevalonic acid can be envisaged as shown (**III**). In this diagram the dotted bonds are those formed in the biosynthesis of farnesyl pyrophosphate and the hatched bonds are those formed by cyclization mechanisms well-charted in terpene biochemistry. The rearrangement of the allylic pyrophosphate double bond has also been reported (Cane and Ha, 1988).

From an agricultural point of view there is therefore hope that this efficient path of mevalonate metabolism can be enhanced at the expense of that of trichodiene and recent mapping of the genes involved (Hohn et al., 1995) lends substance to this expectation.

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REPORT OF THE REGIONAL MEETING ON MATERIALS SCIENCE RESEARCH AND FACILITIES, 1994

Introduction

In the fall of 1994, scientists and engineers in the region with interests in materials science were asked to meet informally to discuss research interests. The meeting was held December 13, 1994, at the Department of Chemistry, Dalhousie University.

Materials Science in Nova Scotia

Twenty seven participants from ten departments representing four institutions attended the meeting. From further expressions of interest, this could be estimated to represent about 50% of the materials scientists in the region. Although it is difficult to categorize materials research, especially since it can be done in terms of materials and in terms of properties, some attempt at categorization has been made, if only to provide key-words. Of course, direct contact with the researchers themselves will be the best means to obtain complete information. For that reason, researchers' names are provided (parenthetically in CAPITAL LETTERS), and complete contact information is given in the Appendix. Headings and subheadings are alphabetically ordered, with no attempt to quantify the level of activity in any given area.

Research Interests

Ceramics and Composites:

Composite and ceramic analysis (CLARKE and MACKAY)
Grain growth (PACEY)
Microgravity (KAZI)
Metal matrix composites (KIPOUROS)
Modelling (TAHERI)
Slip casting (KAZI, PACEY, YEMENIDJIAN)
Sol-gel processes (KAZI)
Zirconia and other solid electrolyes (PACEY)

Chemical Synthesis:

Synthesis and characterization; new developments in structure and bonding; organometallic and coordination chemistry (BURFORD)

Crystal Growth:

Crystal growth of semiconductors (GELFANDBEIN, LABRIE, OLSON, YEMENIDJIAN)
Theory (DAS)

Electronic, Electrical and Electrochemical Properties:

Cathodic protection (HYATT)
Corrosion (MACINTYRE, RICHTER)
Electron correlation and density (BOYD)
Ionic and electronic conductivity (PACEY)

Magnetic Properties:

Magnetic materials (KIPOUROS)
Magnetic domains (BLACKFORD, JERICHO)
Orientation dependence of nmr parameters (WASYLISHEN)

Mechanical Properties:
Experimental investigations of response of structure and materials, e.g. adhesives (TAHERI)
Fracture mechanics (HYATT)
Indentation studies (BLACKFORD, JERICHO)
Mechanical properties (SZABO)
Testing (MACINTYRE, RICHTER)

Metallurgy:
Analysis (CLARKE, MACKAY)
Metallurgy (HYATT)

Microgravity:
Ceramics and composites (KAZI)
Crystal growth of ternary semiconductors (LABRIE, YEMENIDJIAN)
Theory of crystal growth in microgravity (DAS)

Modelling and Calculations:
Computational modelling of engineered materials, structural components and processes (e.g. plasma spray modelling) using finite element method (TAHERI)
Finite element analysis of simulated structures (KAZI)
Modelling of cathodic protection (HYATT)
Molecular dynamics simulations, especially of molecular liquids, e.g. water (KUSALIK)
Quantum chemistry (e.g. energetic materials), surface chemistry, reaction mechanisms and dynamics (BOYD)
Theory of crystal growth in microgravity, diffusive processes (DAS)

Optical Properties:
Second-harmonic generation in electro-optic crystals (PATON)

Other areas:
Automated inspection (HYATT)
Fire protection (SZABO)
Forensics (MACINTYRE, RICHTER)

Other systems:
Inorganic materials (BURFORD, WASYLISHEN)
Orientationally disordered materials (WASYLISHEN, WHITE)
Polymers (SZABO)

Semiconductors:
Crystal growth of semiconductors (GELFANDBEIN, LABRIE, OLSON, YEMENIDJIAN)
Analysis (CLARKE, MACKAY)

Surfaces and Coatings:
Coatings (SZABO)
Deposition of coatings for space, medical and dental applications (PASS)
In situ high-resolution experimental studies of surfaces (smaller than 5mm), surface roughness (BLACKFORD, JERICHO)

Thermal Properties:
Heat capacity, thermal conductivity, phase transitions (WHITE)
Thermal analysis (SZABO)

Research Equipment:

Acoustic characterization (SZABO)
Arc plasma deposition of coatings (GELFANDBEIN, OLSON, PASS)
Ceramic fabrication equipment (LABRIE)
Ceramic processing (KAZI)
Chemical vapour deposition (PACEY)
Cold press and powder preparation (KIPOUROS)
Computational facilities: Stellar GS 2500 vector processor and IBM RS/6000 models 355 and 580 (BOYD)
Corrosion testing facilities (HYATT)
Densitometers (KIPOUROS)
Dielectric equipment (WHITE)
Electron microprobe and image analysis for rapid non-destructive quantitative chemical analysis of minerals, glasses and metals in grains as small as 5 μm, elements from O to U (MACKAY, CLARKE)
Environmental testing (KAZI)
Erosion testing (KAZI)
Floating-zone crystal growth equipment (LABRIE)
Furnaces (KIPOUROS, YEMENIDJIAN)
Glove boxes (BURFORD, KAPOUROS, YEMENIDJIAN)
Heat capacity calorimeters (WHITE)
Infrared spectrometers (BURFORD, LABRIE, SZABO)
Laser sources from 331 nm to 1550 nm (PATON)
Laser writing (PATON)
Mass spectrometry: CEC 21-110 mass spectrometer and VG Quattro triple quadrupole mass spectrometer (GROSSERT)
Metallographic preparation facilities (HYATT)
Metallography equipment (KAPOUROS)
Mechanical strength and hardness (HYATT, KAZI, KIPOUROS)
Nuclear magnetic resonance (nmr) spectrometers: MSL-200 nmr spectrometer and AMX-400 nmr spectrometer (WASYLISHEN)
Optical benches (PATON)
Pyrolysis-Gas chromatography/Mass spectrometry (SZABO)
Raman spectrometers (BURFORD, KIPOUROS)
Reactor for powder production (KAZI)
Resistivity and Hall effect equipment (LABRIE)
Rheometers (KIPOUROS)
Scanning electron microscope (KIPOUROS)
Scanning tunneling microscopy and atomic force microscopy (BLACKFORD, JERICHO)
Slip casting equipment (YEMENIDJIAN)
Thermal analysis: DMA, TGA, DSC, Dielectric (SZABO); DSC (WHITE)
Thermal conductivity equipment (WHITE)
Thin film deposition (LABRIE)
Viscometers (KIPOUROS)
X-Ray powder diffraction (LABRIE, SZABO)

Acknowledgements

This meeting was supported by the Nova Scotian Institute of Science and the Department of Chemistry, Dalhousie University. Thanks are extended to those who took the time to make the meeting a success.

Appendix

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Mary Anne White

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PRESIDENT'S REPORT 1993-94

In the 1993/94 season the Institute presented the following lectures and a panel discussion:

October:	Halifax Harbour Cleanup: Where to now? Alan Ruffman, Geomarine Associates
November:	Science Education: Is it doing the right job and is it doing it well? A Panel Discussion with Elinor Nicoll, Howard Dickson, John Haysom and Hector Jacques
December:	The Million Dollar Fish and the Bionic Tomato. Robert Fournier, Dalhousie University
January:	Tragedy of Quota Management for Groundfish Fisheries: The Scotia-Fundy Example. Michael Sinclair, Dept. of Fisheries & Oceans
February:	Observations from the COBE Satellite: Implications for the Theory of the Big Bang and the Question of Missing Matter. K.A. Dunn, Mathematics Dept., Dalhousie Univ.
March:	The Lobster Fishery: from boom to bust to....? John Pringle, Halifax Fisheries Research Laboratory
April:	Advanced Reproductive Technology and the Royal Commission. Gillian Graves, Endocrine & Fertility Clinic, Grace Maternity Hospital and Dalhousie University

Attendance at the various lectures was up for the year drawing around 50 or more people for most meetings. The panel discussion on Science Education was also well attended and the lively discussion on this important topic was a further step in the examination of science in general eg., strategies, research quality, funding and education.

The drive made over the last two years to bolster membership has resulted in a substantial number of new members. Contacts have been maintained and, in fact, increased with the Science teachers through the efforts of their Observer, Ed Kelly and Council Member, John Pringle. In addition links with the Discovery Centre have been developed; the Executive Director, Dr. Sally Walker attends Council meetings to provide liaison between the Nova Scotian Institute of Science and the Discovery Centre.

The Institute invited members of the Public Relations course at Mount St. Vincent University to assist us in developing a heightened profile in the community. Two students, Charles Crosby and Paul Moore, undertook this task as a course assignment. They prepared an analysis of the Institute's current activities and then produced a paper

entitled "Media Plan: The Nova Scotian Institute of Science". Their various and wide ranging recommendations included establishing as one of the Council will be moving to put this and other recommendations into effect in the coming year.

The Institute continued its publication series and has added to materials made available by providing diskettes (for sale) on a microbiological culture collection. The Editor stated that this last activity has netted the Institute significant additional income. Consideration is being given to other ventures of a similar nature to expand income for publication and library needs.

Financially the Treasurer reported the Institute is in reasonable shape although its publication costs always match and frequently exceed, the annual membership fees. Because of this and the need to have funds to expand activities the Council is proposing, at the 1994 Annual General Meeting, an increase in annual membership fees.

The Librarian informed the Council that the number of institutional and exchange partners remained relatively constant. A problem has arisen, however, concerning the housing of the Institute's library. Currently this is held in the Dalhousie University library system through an agreement arranged between Dalhousie University and the Institute. Unfortunately cuts in the university budget have resulted in a restructuring there and a request for us to review and revise our holdings with a view to reducing costs. The Council has appointed the Editor, Alan Taylor to chair a committee to review the situation and to make recommendations for implementation during the coming Institute season. At this time we wish to offer our thanks to Dalhousie University for their cooperation and support in housing the Institute's collection and making it available for community use.

On behalf of the Institute I wish to acknowledge the financial support given by the Nova Scotian Museum for publication of the Proceedings and to thank the Museum for this and for the provision of space and facilities for the monthly meetings of the Institute.

In conclusion I thank the members of the Council of the Institute for their time and effort over the past year. I have enjoyed the association and am grateful for their support which has made the past season a very positive one and resulted in considerable progress in Institute affairs.

Submitted by:

James E. Stewart

PRESIDENT'S REPORT 1994-95

The Nova Scotian Institute of Science has three main activities—regular lectures, publication of *The Proceedings,* and its library—and one additional role—as a collective voice for scientists in Nova Scotia. The Institute has been active this year on all fronts.

We had an outstanding series of lectures this year: "Ten Equations that Changed the World" (Professor S. Swaminathan, Dalhousie University), "Origins and Diversity of the Protists: the Other 95% of the Eukaryotes" (Dr. Mark Ragan, National Research Council), "Computer Vision and Image Processing" (Professor Peter Gregson, Technical University of Nova Scotia), "A Century of X-Ray: Medical or Scientific Uses" (Professor Stan Cameron, Dalhousie University), "DNA: The Ultimate Determinant of Identity" (Professor Jonathan Wright, Dalhousie University), "Creativity and the Two Cultures Revisited" (Professor Paul Patterson, University College of Cape Breton). In addition, we had a spirited panel discussion "Science Curriculum in Schools" with Professor Mary Anne White (Dalhousie University) and Adriane Dorrington and Bob LeBlanc (both from Department of Education and Culture) as panellists and Tom Nickerson as moderator. We are grateful to all who took the time to contribute to our program.

Although no issues of *The Proceedings* were published this year, plans have been launched to publish an issue in memory of the late Professor Walter J. Chute (NSIS President 1952-54). In addition, we have reached an agreement with the Nova Scotia Museum of Natural History concerning commission sales of selected back issues of *The Proceedings.*

Through exchange of *The Proceedings* with other learned societies, the Institute has built up a remarkable Library. For several years the Library has been located in (and maintained by) the Killam Library at Dalhousie University. Dr. Fred Kennedy has kindly put together a very nice display in the Killam Library concerning the Institute's collection, and I commend it to you. The Institute has agreed to contribute towards hiring a student this summer, in order assess our holdings.

In December, the Institute sponsored a meeting of materials scientists in the region. The purpose of this meeting was to bring together scientists and engineers with common interest, in order to foster exchange of information. A Report, to be published in *The Proceedings,* will list areas of materials science research in the region, equipment for materials science research, and the names and addresses of those who attended the meeting.

Inspired by the materials science meeting, one of our members, Professor J.S. Grossert, suggested that the Institute prepare a directory of scientific research facilities in Nova Scotia. Dr. H. Stan Heaps has kindly agreed to undertake this venture, which

should be complete in a few months. The directory will be published in *The Proceedings*, and also made available electronically.

Much attention is currently paid to the state of scientific research activity and funding. On behalf of the members of the Institute, I have corresponded with appropriate government officials, expressing our support for science, especially as an investment in the future of this country.

As this year draws to a close, it remains to express my thanks: to the members of Council, especially the retiring members, Dr. A. Taylor (Editor), S. Fullerton (Librarian) and Dr. J. Stewart (Past President); to the Museum for support of our activities; and especially to Anne Seller who worked hard, combatting virtual indifference in the media, to increase the publicity of the Institute's activities.

Finally, a word to the members: The Council has many times discussed the role and purpose of the Institute, especially in light of declining membership. It is *your* Institute; if you have an idea will benefit science and scientists in Nova Scotia, please bring it forward.

Respectfully submitted,

Mary Anne White, BSc, PhD
May 1, 1995

PRESIDENT'S REPORT 1995-96

During the year 1995-96,the Nova Scotian Institute of Science presented six lectures and two panel discussions. The quality of all lectures was very high. The panel discussions were very exciting and stimulating. Both the panel discussions brought awareness of the issues of the day to the members. We are grateful to all those who took the time to contribute to our programs. The lectures and panel discussions are listed below:

October 1996:	Panel Discussion on Science Policy Issues (Panelists Professor William Tatton, Dalhousie Univ., Dr. Michael Winther, Efamol, Dr. Roger Foxal, NRC, and Dr. Ted Rhodes, TUNS)
November 1995:	Supernova Scotia: (David Lane and Paul Gray, SMU).
December 1995:	Piping Plover Guardian Program: (Ms. Cathy Fulton Strugnell)
	January 1996: Panel Discussion "Reproduction Technology & Its Ethics" (Panelists: Dr. William Wrixon, Dr. Barbara Parish and Dr. Susan Sherwin,Dalhousie University.)
February 1996:	"Medicine and Disease - 100 years ago" (John Farley, DAL Univ.)
March 1996:	"Production of Phycotoxins"(Dr. James E. Stewart, BIO.)
April 1996:	"The Statistics of Counting Birds and other Things : Poisson Model" (Professor C.A. Field, DAL Univ.)

All the lectures and panel discussions in 1996 were taped and broadcast on local television. We received several good comments. We hope that NSIS will be able to have its own TV show on the local cable television station.

Professor Stan Heaps created a Home Page for the Nova Scotian Institute of Science on the Chebucto Community Net. It contains links to a history of NSIS, the list of Council members, the times of meetings, the periodical titles in the NSIS library, and the directory of research facilities in Nova Scotia.

Professor Stan Heaps also completed a NSIS Sciences Research Facilities survey. He prepared a database in a form that can be accessed on WorldWideWeb through Internet. The database contains: Facility Directory that contains link to an Equipment list, a key word list and a company list.

The Institute formed a development committee consisting of R.P. Gupta, M. A. White, John Pringle and G. Stroink (chair). The committee identified many issues: to assess the weakness and strength of NSIS; to tackle topics relevant to decisions in Nova Scotia; to obtain more publicity for the Institute; to help develop a science policy in Nova Scotia, and to broaden the scope of our journal, the Proceedings of the Institute.

The Chute Volume of the Proceedings of NSIS was published in January 1996. Another issue on material science will be mailed in July. The Editorial board of the NSIS

proceedings has been reconstituted with Dr. Derek Davis as the editor and Dr. D. Reardon (T.U.N.S), Dr. Donald D. Betts (Dalhousie) and Dr. Stan Heaps and Dr. John Tremblay (Fisheries and Ocean) as the members of the Editorial Board.

The Nova Scotian Institute of Science has a very valuable collection of scientific material, based in the Killam library of Dalhousie University. Some of the collection was not catalogued. In May,1995, a student was hired to review the Institute's collection. Decisions were made on a title by title basis whether to retain or withdraw some of the material. The withdrawn material will be sent to the Canada Institute for Scientific and Technical Information. The project will continue during the summer of 1996. The catalogued material is available on NOVANET. Our sincere thanks to Ms. Sharon Longard for looking after the NSIS collection.

For the first time, the NSIS conducted a science workshop for grades 5 and 6 students from five schools in the Halifax Regional Municipality. Twenty students, accompanied by their parents attended the workshop at Dalhousie University on April 27, 1996. The workshop was conducted by Mr. Surjeet Varma, a retired Science Curriculum Supervisor, Halifax County Board. By all accounts, it was a great success. The students and their parents enjoyed it very much and they requested that we should organize more workshops in the future.

On behalf of the Institute, I would like to acknowledge the financial support given by the Nova Scotia Museum for publication of the proceedings and thank the Museum for providing the space and facilities for holding our meetings and lectures.

Finally, I wish to thank the members of the Council of the Institute for their cooperation.

Submitted by:

R.P. Gupta
May 3, 1996

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of the

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The Editor will consider for publication articles of general or specific science interest. Papers which develop scientific theories based upon scientific principles and/or analysis of data pertaining to Nova Scotia/or Atlantic provinces are particularly encouraged.

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ECOLOGICAL CONSIDERATIONS FOR PROTECTED AREA SYSTEM DESIGN

The need for an integrated approach to maintaining biological diversity

KAREN BEAZLEY

Abstract: Island biogeography, conservation biology, landscape ecology, paleoecology, non-equilibrium ecology, and hierarchy theory provide insight into protected area system design. Ecological criteria may be identified for site selection and boundary delineation. Considerations of viable populations, critical habitat area, patch dynamics, and landscape context address the question of how much area is required to maintain biological diversity. Strategic methodologies integrating autecological, biogeographical, population viability and gap analyses provide context specific information for designing protected area systems. Biosphere reserve, node and corridor, and greater ecosystem models, and wilderness recovery, triad, coarse- and fine-filter, and target species approaches integrate protected area systems into broader sustainable regional landscapes.

Key words: protected areas, design, biological diversity, viable populations, ecological considerations

Introduction

Historically, parks and protected areas have been established with little contribution from ecological science. Consideration of ecological criteria could improve park and protected area system design for conservation objectives such as the maintenance of current levels of native biological diversity (biodiversity).

Through various conventions, agreements and initiatives, Canada and the Province of Nova Scotia have made commitments to maintaining biodiversity. Parks Canada has a mandate to maintain ecological integrity and complete a system of parks to represent the natural regions in Canada (Canadian Heritage 1994). The Province of Nova Scotia is currently in the process of delineating and establishing a province-wide parks and protected areas system (NSDNR 1994). There is much interest in how these objectives may best be accomplished.

This paper examines ideas from ecological science that provide insight into protected area system design. These include island biogeography, viable populations and critical habitat area, patch dynamics, landscape ecology, paleoecology, and non-equilibrium perspectives. The focus is on ecological considerations that address the question of how much area is required to maintain current levels of native biological diversity over time. The need for strategic and multiple integrated methodologies in planning and designing protected area systems is demonstrated. A selection of methodologies and their relationship to each other is described. Finally, design and planning concepts are introduced, along with approaches for integrating protected areas into the broader regional context.

The Role of Protected Areas

Protected areas have been established for various purposes. In examining the role of protected areas in maintaining biological diversity, many questions arise. For example, are protected areas *alone* expected to fulfill this role? And, are they intended to fulfill this role in perpetuity? If the answer is "yes" to these questions, then the prospects for biodiversity are grim. Existing protected areas are too few, too small and

too isolated to enable most large mammals to persist in the shorter term, and many species will be lost over the longer term. Protected areas must work in concert with surrounding working landscapes to maintain biodiversity.

Protected areas have been variously defined as, "an area of land which has effectively been removed from the development stream for the purpose of perpetuating natural conditions", the central role being to protect natural diversity (Pyle 1980, 319); "a region set aside for the protection of the aggregate of species contained therein, as well as the supporting physical environment . . . to maintain, hopefully for perpetuity, a highly complex set of ecological, genetic, behavioral, evolutionary and physical processes and the co-evolved, compatible populations which participate in these processes" (Frankel and Soulé 1981, 98). More simply, "protected areas provide a repository for species and their gene pools, together with the natural selective forces that mould them" (Theberge 1993, 138). Protected areas may also refer to "biological management areas" within landscapes that are not strictly "protected", wherein human activities compatible with conservation objectives take place (Scott et al. 1993).

Theoretical Contributions to Protected Area System Design

Lessons from Island Biogeography

Island biogeography theories have led to applications of its models to terrestrial habitat "islands" and protected area design. Island biogeography theory suggests that species numbers will be larger on larger oceanic islands due to the species-area relationship (Preston 1960), and on islands closer to a continental land mass due to the distance or isolation effects of the equilibrium model (MacArthur and Wilson 1967). Principles for the design of terrestrial protected areas based on island biogeography were proposed (Diamond 1975), widely disputed and largely discredited (Soulé and Simberloff 1986; Margules et al. 1982; Shafer 1990). Substantial debate ensued about whether a single large protected area or several small protected areas (SLOSS) of equal total area would capture more species (for an overview see Shafer 1990).

Theoretical and empirical evidence has been presented both to support and dispute the theories, general design principles, and SLOSS arguments. The resolution seems to be that undue emphasis should not be placed on the application of general rules to the practice of conservation but, in most cases, a large protected area will capture more species than a small one. However, small protected areas are important to capture rare or endemic species with limited distribution. There are benefits to having several protected areas rather than a single one, for example: to reduce effects of disturbances such as disease, fire and pests; to maximize genetic diversity; to provide redundancy; and, to increase habitat variability, and environmental and biological diversity. However, several small protected areas may not protect wide-ranging species, interior species, those sensitive to human interference, and viable populations.

Several reasons have been given for the perceived deficiencies of island biogeographic theory for application to protected area design. The equilibrium theory has not been sufficiently tested and seems to hold true in a few systems and not in others; the species-area relationship is not best explained by the dynamic equilibrium theory and probably is affected primarily by the fact that larger sites tend to have more habitats; and, scientific findings from one system are not necessarily applicable in another (Margules et al. 1982; Soulé and Simberloff 1986). In regards to SLOSS, whether a single large or several small protected areas would capture more species is more likely to be explained by heterogeneity of habitat than by area considerations alone.

Shafer (1990) compiled a set of guidelines for the design of protected areas from consensus in the literature. Table I provides a selection of these guidelines. However, general guidelines should be applied with caution and with respect to the particular context. Decisions should be based on field studies, with a major consideration being to conserve enough habitat for the target species. This view reflects a "pre-equilibrium theory" idea of effective protected area design and supports a return to autecological and context specific research (Soulé and Simberloff 1986; Shafer 1990; Pickett et al. 1992).

Table I Selected Guidelines for Protected Area Design

- The more land you set aside, the more species you will preserve.
- A larger area usually captures more species of plants and animals, but returns typically diminish as area increases beyond a certain point.
- Habitat fragmentation and protected area insularization should be discouraged.
- Protected area boundaries should not create abrupt transitions that discourage animal movement to surrounding habitat.
- A large protected area is better than a small one, everything else being equal.
- Many large protected areas are needed in as many biotic communities as possible.
- Small protected areas can serve a useful purpose in any overall system design to conserve some species or to facilitate migration of other species.
- Small populations should be avoided; populations should be as large as possible, and should be replicated.
- Rare species and large-bodied, wide-ranging species are likely to be the most vulnerable to extinction.
- The establishment of corridors to facilitate animal movement should be based on autecological study of individual species and individual situations.
- The establishment of a new protected area should be based on studies of the distribution of species and communities in the region or country to avoid the sample effect.
- Autecological studies of individual species and their relationship to other species should be given a high priority.
- Protected areas for large mammals should usually be increased in size where opportunities exist to do so; buffer zones are an alternative.
- Under ideal conditions, protected area size should be such as to accommodate the largest, widest-ranging mammals, on the basis of their life history and territorial behavior, and will then serve as an area umbrella for other species.
- Protected area design should seek the theoretical ideal of maximizing alleles by preventing genetic drift in small populations and of preserving heterozygosity by discouraging inbreeding.
- Smaller protected areas probably will withstand less internal or external stress than larger ones.
- The design and management of protected areas should be viewed as potentially an interactive regional matrix.

(Source: Selected from Shafer 1990)

The distinction between site selection and boundary delineation

Selecting and evaluating protected areas from within a broader region requires quite different processes and criteria than for delineating a protected area boundary once a site has been selected. Both site selection and boundary delineation are part of the design process of a protected area system and relate to the question of how large of an

area is required to maintain biodiversity. While site selection criteria will be briefly described, the main focus in this paper will be on boundary delineation.

Site Selection Criteria for site selection are well documented. The most commonly stated reasons for establishing and selecting protected areas are to conserve diversity of habitats and species, and characteristics of rarity or uniqueness, naturalness, representativeness, and large size (Table II). A procedure for selecting protected areas may consider various criteria in stages: 1) pre-evaluation classification or sorting stage; 2) representativeness; 3) threshold criteria (naturalness, area); 4) ranking criteria (diversity, rarity, or any other ecological criteria); and, 5) pragmatic criteria such as threat of interference (Margules 1986; Usher 1986).

Table II Evaluation criteria for assessing and selecting protected area sites

Margules and Usher (1981)	Smith and Theberge (1986)	Usher (1986)
Diversity	Rarity, Uniqueness	Diversity (habitats and/or species)
Rarity	Diversity	Naturalness
Naturalness	Size	Rarity (habitats and/or species)
Area	Naturalness	Area
Threat of human interference	Productivity	Threat of human interference
Typicalness or representativeness	Fragility	Amenity value
Educational Value	Representativeness, typicalness	Education value
Amenity value	Importance to wildlife, abundance	Representativeness
Recorded history	Threat	Scientific value
Scientific value	Educational value	Recorded history
Uniqueness	Recorded history / research investment	Population size
Wildlife reservoir potential	Scientific value	Typicalness
Ecological fragility	Recreational value	Ecological fragility, position in ecological / geographical unit
Position in ecological/ geographical unit	Level of significance	Potential value
Potential value	Consideration of buffers and boundaries	Uniqueness
Availability	Ecological/geographical location	Archaeological interest
Replaceability	Accessibility	Availability
Management consideration	Conservation effectiveness	Importance for migratory waterfowl
	Cultural resources	Management factors
	Shape	Replaceability
		Silviculture gene bank
		Successional stage
		Wildlife reservoir potential

* Criteria listed in order of frequency of use *(Compiled from Margules and Usher 1981; Usher 1986; and Smith and Theberge 1986; 1987)*

Currently in Canada, most protected areas are established with the objective of representing the biophysical regions of the particular planning jurisdiction. Both Parks Canada and the Province of Nova Scotia use "representivity" as a primary criteria for site selection (Canadian Heritage 1994; NSDNR 1994). Selecting representative protected areas requires that the jurisdiction be classified into regions. Approaches for classification can be of various types. Environmental approaches are based on climatic

regions or a combination of land form, soils, lithology, vegetation and climate. Biological approaches focus on floristics, species distribution or biogeographic regions, or vegetation communities distribution (Usher 1986). World Wildlife Fund's (Canada) gap analysis for assessing respresentivity supports an "environmental" classification approach (Iacobelli et al.). Nova Scotia's Department of Natural Resources utilized a combined approach, identifying 77 natural landscapes in Nova Scotia (NSDNR 1994).

Boundary Delineation Many protected areas were originally created within areas of larger similar "wilderness" and for reasons unrelated to ecological integrity or biodiversity, such as scenic beauty, recreation or tourism. As the surrounding wilderness disappears, boundary issues become more critical in terms of conservation objectives. Greater protection inside the protected area results in a "generated edge" that reflects changes that occur along and across the boundary in human behavior and in species and resource distribution (Schonewald-Cox and Bayless 1986). If the generated edge is inside the protected area, effective size is reduced.

In eight of the largest protected areas in western Canada and the United States, the legal protected area boundaries are smaller than the "biotic boundaries". Biotic boundaries are "those necessary to maintain existing ecological processes and a given assemblage of species within a National Park" (Newmark 1985, 197). As these protected areas become increasingly insularized by surrounding land-use change they may experience faunal collapse.

Protected area boundaries need to be compatible with ecological realities to maintain biodiversity. Theberge (1989) described abiotic, biotic and cultural guidelines for delineating ecologically sound boundaries (Table III). These guidelines may be adapted for particular applications with consideration of the specific biogeographic context.

Table III Guidelines for drawing ecologically sound boundaries

Abiotic Guidelines

1. encompass the greatest possible proportion of the area drained by the river of highest order
2. include headwater areas
3. consider subsurface transbasin water flow
4. should not cross active terrain
5. include rare geomorphic and hydrologic features and processes

Biotic Guidelines

Community level:

6. should not sever rare or unique communities
7. should not sever highly diverse communities
8. should not sever communities with a high proportion of dependent faunal species

Species level:

9. should not jeopardize the ecological requirements of either numerically rare or distributionally rare (uncommon) species
10. should not jeopardize the ecological requirements of niche specialists
11. should not jeopardize populations of spatially vulnerable species
12. should not jeopardize populations of *k*-selected species
13. should not jeopardize populations of range-edge or disjunct species
14. should take into special account pollution-susceptible species
15. should take into special account the ecological requirements of ungulate species

Note: Cultural guidelines have been omitted
(Source: compiled from Theberge 1989)

Ecological Considerations for Determining Area Requirements

It is generally agreed that what is needed is as many, as large and as connected protected areas as possible. However, in light of the increasing competition for land resources, as well as demands for guidelines from protected area designers and managers, the idea that "bigger is better" must be refined to more precise prescriptions for how much area is enough to maintain biodiversity. This question remains unanswered. E.O. Wilson was referring to the task of determining the minimum area required to retain native biodiversity when he stated that "no process being addressed by modern science is more complicated or, in my opinion, more important" (1984 in Shafer 1990).

The ecological considerations in this process are complex and interrelated. However, they can be organized into three broad groups: 1) viable population and critical area; 2) patch dynamics and disturbance regimes; and, 3) landscape level considerations. These considerations may be informed by paleoecology and non-equilibrium perspectives.

Viable Populations and Critical Habitat Area

If the aim of protected areas is to preserve the processes of evolution in perpetuity rather than the present diversity of species *per se* , then the forces that affect species extinction and evolution must be considered. Factors leading to extinction include systematic pressures and stochastic perturbations. Protected areas remove or compensate for systematic pressures, however sources of uncertainty remain to which a population may be subject: demographic, genetic, and environmental stochasticity; natural catastrophes; and, dysfunction of social behavior at small population sizes (Shaffer 1981; Soulé 1983 in Boecklen 1986) (Table IV). A minimum viable population (MVP) is one which has a high probability (for example, a 99% chance) of enduring these sources of uncertainty within the context of its own particular biogeographic context, over a relative time frame (for example, 1000 years) (Shaffer 1981).

Table IV Sources of Uncertainty Threatening Species Persistence

Extrinsic factors:
Environmental stochasticity due to deleterious changes in habitat parameters and the populations of competitors, predators, parasites, and diseases;
Natural catastrophes, such as floods, fires, droughts, which may occur at random intervals through time;
Intrinsic factors:
Demographic stochasticity, which arises from chance events in the survival and reproductive success of a finite number of individuals, such as random variations in sex ratios or birth and death ratios;
Genetic stochasticity resulting from changes in gene frequencies due to founder effect, random fixation, or inbreeding;
Social dysfunction or behaviors that become maladaptive at small population sizes.
(Compiled from Shaffer 1981; and Soulé 1983 in Soulé and Simberloff 1986)

Genetic criteria have provided some understanding for minimum viable population calculations and protected area design (Shaffer 1981; Boecklen 1986; Shaffer 1990; Soulé and Simberloff 1986; Grumbine 1990a; Soulé 1980; Frankel and Soulé 1981).

The two aims of genetic conservation (preservation of heterozygosity and preservation of alleles) may be antithetical from a protected area design standpoint. Alleles are best maintained in subdivided populations with no migration, and heterozygosity is best preserved over the short term in intact populations and over the long term in subdivided populations with high rates of migration. It may not be possible to maintain sufficient numbers of individuals of some species at the present time, with the protected areas we have or are likely to establish in the near future, to allow evolutionary changes (Frankel and Soulé 1981; Soulé and Wilcox 1980). The best short-term objective may be to maintain enough genetic fitness for short term survival of species in order to maintain enough evolutionary potential for long term survival, in the hope that future protected area and land-use planning may leave enough space for ecological processes to reestablish an equilibrium (Frankel and Soulé 1981). Therefore, preservation of alleles should have the higher priority because heterozygosity can be reconstituted by increasing gene flow in the future or artificially. Thus, several protected areas and populations with occasional migrations among them may represent the optimal design strategy for genetic conservation (Franklin 1980; Boecklen 1986).

There are lower limits to the size of sub-populations where extinction probabilities increase, and these lower limits should not be violated. Although there is no "magic number" applicable to all species, Franklin estimated that, from inbreeding considerations alone, a minimum effective population of 50 is needed for short-term, and 500 for long-term survival (1980, 147). It is important to note that *effective* population size is significantly lower than census or total population size, because it assumes an *ideal* breeding population. Effective population size (Ne) may also be higher if other sources of uncertainty are considered along with inbreeding considerations. Further, Franklin's numbers were determined using the 1% rule of maximum tolerable rate of inbreeding developed by domestic animal breeders; effective population sizes for wild species in natural habitats may be significantly higher than Ne=50.

Clearly, minimum viable population size would be higher than effective population size, both in the short- and long-term. Franklin's numbers have been disputed: they are probably only correct in that they are within the right order of magnitude for most species; and, they are probably too low for real or wild populations (Grumbine 1990a; Lande and Barrowclough 1987 in Grumbine 1990 a). Thus, these figures could be dangerous if used as protected area design criteria. Subsequent estimates suggest that a short-term (50-100 years) minimum viable population for wolves is 148 breeding individuals, and for grizzly bears is 393 (Hummel and Pettigrew 1991).

Considerations of viable populations and critical habitat area should ideally be based on long-term survival, thus utilizing figures in the order of magnitude of Ne=500 and applying it to a target species. Minimum critical area (MCA) is determined by calculating the amount of habitat required to sustain the minimum viable population, including home range and migration patterns. The minimum critical area required to protect a viable population has been calculated as approximately 39,000-78,000 km^2 for wolves (Frankel and Soulé 1981, 122), and 12,233-122,330 km^2 for grizzly bears, depending on the location of the habitat (Craighead and Mitchell 1982 in Newmark 1985; Hummel and Pettigrew 1991).

Large mammals, particularly carnivores, are appropriate target species for area requirement calculations because as a group they tend to be sensitive indicators, vulnerable due to their low densities, and important or keystone in their communities. As well, they act as "umbrella" species, encompassing many other species with smaller area requirements (Frankel and Soulé, 1981; Hunter, 1990; Noss, 1990). Thus, protected areas are generally too small: 93% of all protected areas in the world are less

than 5000 km^2, and 78% are less than 1000 km^2 (IUCN in Frankel and Soulé 1981, 129).

A methodology for determining protected area size is to: 1) identify target or keystone species; 2) determine the minimum number of individuals needed for survival; and, 3) estimate the area needed to sustain the minimum number, ensuring that: a) enough habitat exists to support the number of individuals in a population needed to guarantee a high probability of survival over a long time period; and, b) the dynamics of succession do not eliminate critical habitat (Soulé and Simberloff 1986).

Population Viability Analysis

Population viability analysis (PVA) is a tool for determining MVP and MCA by incorporating biogeographic distribution patterns, species-specific turnover rates and available population data into computer simulations designed to test extinction probabilities (Gilpin and Soulé 1986). Earlier population viability analyses focused on *demographic approaches* (MacArthur and Wilson 1967), while later studies focused on *genetic aspects* (Frankel and Soulé 1981; Gilpin and Soulé 1986) and environmental factors such as patch dynamics (Pickett and Thompson 1978). A combination of approaches is necessary to provide an integrated model of all the factors of extinction, but such a model may be too complex to use.

Population viability analysis encompasses at least three fields: 1) population phenotype; 2) environment-habitat quality and quantity; and, 3) population - structure and fitness. For PVAs associated with protected areas, the disturbance regime is often the most important factor in the environment because populations may be restricted to island-like habitats and be unable to escape to other suitable habitat areas (Gilpin and Soulé 1986). Thus, PVA requires the consideration of the biogeographic context, particularly patch dynamics and landscape structure. Meta-population viability analysis incorporates considerations of regional sub-population groups (meta-populations) and their relationships.

Minimum Dynamic Area and Effective Protected Area Size

Succession and disturbance regimes such as fire, windstorm, disease and herbivory are often the most significant aspects of the environment. These processes at various spatial and temporal scales across the landscape determine the size, density and temporal frequency of patches and result in heterogeneous patches or "patch dynamics" (Pickett and Thompson 1978) which together over time and space represent a "shifting mosaic steady state" (Bormann and Likens 1979). Patch dynamics should be considered in the design of protected areas because some species in protected areas may not be able to disperse to new sites in the face of disturbances that threaten their survival. Further, patch dynamics are ecological processes which create diverse habitat, resources and communities. Protected areas should allow for these processes, therefore consideration of disturbance regimes, including rare events and the associated patterns of succession, is required.

The design of protected areas should be based on analysis of the minimum dynamic area (MDA). MDA is "the smallest area with a natural disturbance regime, which maintains internal recolonization sources, and hence minimizes extinction" (Pickett and Thompson 1978, 34). In a protected area, the minimum dynamic area should be defined relative to the target species. In other words, viable population and critical area requirements must be combined with patch dynamic consideration to make decisions on effective protected area size. Protected areas should be large enough to contain regionally specific processes such as tree falls, wind throws, fire and disease, without

affecting all of the habitat of any particular type. In the face of disturbances enough habitat should remain to support a minimum viable population of the target species.

Biogeographic Context and Regional Landscape Ecology

Protected areas alone will not preserve the present levels of native biological diversity, let alone provide for evolutionary speciation. Very few, if any, protected areas are large, connected and protected enough to support viable populations of large mammals or encompass minimum dynamic areas. Regardless of the care we exercise in utilizing ecological criteria, protected area boundaries are unlikely to remain congruent with biotic boundaries over time.

Species, materials and processes cross protected area boundaries in both directions. The ecological integrity of most protected areas will depend upon the suitability of surrounding lands as supplemental habitat, migration and dispersal routes and buffers. The maintenance of biodiversity will require utilization of protected areas and non-protected areas as habitat. For these reasons, protected area and broader land-use planning must be integrated to maintain biodiversity.

Protected area design should take into account potential edge-, buffer- and isolation- or connectivity- effects of surrounding land-uses and land-cover. At the landscape level, habitat fragmentation remains the principle threat to most species in the temperate zone (Wilcove et al. 1986). Fragmentation reduces habitat area and results in the redistribution of communities or populations into disjunct fragments. The various effects of fragmentation have been widely discussed (Wilcove et al. 1986; Burgess and Sharpe 1981; Harris 1984; 1988; Soulé 1986: Yahner 1988; Harris and Silva-Lopez 1992).

Recognition of the threat of fragmentation has resulted in debate about the potential role of corridors for migration and dispersal, including wide corridors for dispersal in response to climate change (Forman and Godron 1986; Noss 1987; Simberloff and Cox 1987; Shafer 1990; Peters and Darling 1985; Graham 1988; Hunter et al. 1988). However, the value of corridors *per se* is debatable, because characteristics that define an effective corridor vary according to the species in question; a corridor for some species may constitute a barrier for others. "Connectivity" may be a more useful concept than that of corridors; it is generally beneficial to maintain and restore pre-existing connections among protected areas. Areas which provide connectivity among protected areas include buffer zones, riparian strips, and areas of compatible land-uses.

Buffer zones provide a transition zone between protected areas and intensely used lands. They can increase the effective protected area, provide increased connectivity, and ameliorate boundary- or edge- effects. Considerations that have been used to determine buffer zones include: 1) the need of threatened wildlife species for resources outside of the protected area; 2) the need for buffer zones to serve other protective functions; 3) the need to contain wildlife species likely to move outside of the protected area; 4) the reasonable needs of the local people; and, 5) the amount of land actually available for buffer use (Mwalyosi 1991). These criteria are very general, however context specific criteria could be derived from biogeographical and population viability analysis for particular applications.

Integrative Theoretical Perspectives

Paleoecology

Paleoecology gives insight into considerations of long-term processes such as

climate change and lends support to the coarse-filter approach of protecting areas representative of physical environment variability. Long-term studies of processes show that species respond to environmental changes in individual and novel ways; communities do not respond *in toto*. This suggests that, because biological communities are ephemeral over time, the long term survival of species will depend on their ability to move and survive in response to environmental changes.

Thus an effective protected area system design would focus on protecting representative physical environments rather than biological communities. Protected areas should be located and delineated according to the distribution and range of physical environments; and, should be connected with large-scale corridors with both north-south and east-west orientations to accommodate changes in species distributions in response to shifts in temperature and precipitation patterns. Further, they should be located near the northern limit of species range; in areas of high species diversity; where topography and soil types are diverse; and, in areas containing altitudinal variability. In the case of accelerated climate change due to anthropogenic influences, many species could not disperse fast enough to compensate for climatic shifts and management intervention may be required (Peters and Darling 1985; Hunter et al. 1988; Graham 1988).

The "Non-equilibrium" Paradigm

The "nonequilibrium paradigm" (Pickett et al. 1992) can be characterized as accepting natural systems as open, and emphasizing process. It can be portrayed metaphorically as "patch dynamics" or "shifting mosaic". This paradigm replaces aspects of the classical "equilibrium paradigm" which can be characterized by Clements' (1916) more static concept of the "climax state".

Resulting considerations for protected area design include a recognition of the importance of environmental and historical context, a focus on processes and heterogeneity at various scales, and the inclusion of people as agents of flux and disturbance. The goal of protected area design becomes to maintain the integrity of the processes that have generated the system, specific to the particular historic and biogeographic contexts, rather than attempt to conserve a "slice-in-time" or "static" communities. Natural systems should be viewed as *process*es rather than *entities* (Pickett et al. 1992; Noss 1992). Ecological considerations for protected area system design are suggested in conservation strategies developed from the non-equilibrium perspective (Table V).

Table V Information and strategies applicable to protected area system design

Information to be applied (Pickett et al. 1992):
1 processes governing the system;
2. context in which it is embedded;
3. historical range of flux in the system;
4. evolutionary and physiological limits of the organismal components; and,
5. nature and impacts of episodic and long-term phenomena, including the roles of people
Temporally expanded conservation strategy (Noss 1992):
1. based on long-term ecological and economic sustainability;
2. more dynamic, nonequilibrium view; concentrate on maintaining physical conditions and ecological processes rather than particular species associations;
3. recognize necessity for habitat connectivity and continuity for migration;
4. supplement interest in sustaining existing species with the notion of future evolutionary diversification

(Compiled from Pickett et al. 1992 and Noss. 1992)

Hierarchy Theory

Hierarchy theory provides a useful model for organizing spatial patterns and complex landscape dynamics at various scales. For example, a forest landscape may be understood as a hierarchical system of gaps, stands, watersheds and region. Nonequilibrium dynamics or spatial heterogeneity at one scale can be translated to equilibrium or constancy at a higher level, as in the shifting mosaic steady state (Bormann and Likens 1979) and minimum dynamic area concepts (Pickett and Thompson 1978). It is possible to define or bound an "equilibriating landscape", which is large enough to contain disturbance regimes while maintaining a constant but shifting distribution of patches of all types at all times (Urban et al. 1987).

Shugart and West (1981) simulated a forest "quasi-equilibrium" landscape and determined that the ratio of the "bounded" landscape to the disturbance regime was at least 50:1. Smaller landscapes were referred to as "nonequilibriating". Thus, protected areas should be approximately 50 times larger than the size of the characteristic disturbance regime in order to encompass an equilibriating landscape.

Integrative design and planning concepts

Integrative and strategic approaches to protected area system design include the biosphere reserve model, multiple-use modules, the greater ecosystem concept, wilderness recovery networks, the triad concept, coarse- and fine-filter approaches, and target-species approaches. These approaches have common elements such as buffer zones around core protected areas, linkages with other protected areas and/or the broader region, and cooperative or partnership arrangements with adjacent land owners and managers for furthering protected area values. Multiple-use modules and wilderness recovery plans are more explicit in recommending that connectivity be maintained and restored among "nodes" of protected areas, and, along with the coarse- and fine- filter approaches, include the concept of a larger system or network of protected areas.

The biosphere reserve model (UNESCO/MAB 1974) explicitly calls for integration among strictly protected core areas, buffer areas, and the surrounding zone of influence or cooperation. Research and monitoring to determine effects of human activities on core and buffer areas are integral components. Such research could advance our understanding of processes and causes of change and boundary issues (Francis 1985).

The multiple-use module (MUM) concept has been used to design a protected area system to support wide-ranging species and help reconcile species-level and ecosystem-level approaches (Harris 1984; Noss and Harris 1986). MUMs include nodes of high ecological value that are protected in an inviolable core and that are integrated into a functional regional network through an interconnected system of corridors. Thus, the MUM approach integrates protected areas into the regional context, and extends the focus from species and communities to heterogeneous landscapes.

The greater ecosystem approach attempts to manage protected areas as part of the larger region (Grumbine 1990b). The boundaries of the greater ecosystem often vary with the particular ecological relationships, processes and issues in question. Components of a greater ecosystem approach include: consideration of ecological relation-

ships and hierarchical context; research, monitoring and adaptive management; cooperative and partnership arrangements; and, a recognition that humans are part of the system. The goal is to sustain ecological integrity, including viable populations of native species, evolutionary and ecological processes, and compatible human uses. The greater ecosystem concept is being applied in and around various protected areas in Canada and the United States (Woodley and Freedman 1995; Skibicki 1995).

The wilderness recovery network approach is essentially a land conservation strategy promoted by several conservation biologists (Soulé 1993; Johns 1993; Foreman et al. 1993; Noss 1994). Protected areas with connectivity or linkages among them and buffer zones are delineated at a bioregional level and ultimately could combine to form a continent-wide system. The approach integrates several ecological considerations including representation of all ecosystems, population viability of sensitive species, and perpetuation of ecological and evolutionary processes (Table VI). Estimates of land required to fulfill these considerations range in the order of 25-75 percent of a region, depending on the particular bioregional context (Noss 1994).

Table VI Principles and Approaches for a Wilderness Recovery Plan

A. Set ecological goals
B. Representation
C. Viable populations (especially vulnerable species and large carnivores):
    1. species distribution across their native range
    2. large blocks of habitat containing large populations
    3. blocks of habitat close together
    4. contiguous blocks rather than fragmented
    5. interconnected blocks rather than isolated
    6. roadless blocks and blocks inaccessible to humans
D. Maintain ecological and evolutionary processes, allowing for change
E. Land Conservation:
    1. protect populations of rare and endangered species
    2. maintain healthy populations of species that play critical roles
    3. protect examples of all communities
    4. manage greater ecosystems and landscapes for conservation and sustainability
F. Reconnaissance and selection of core protected areas:
    1. select areas in roadless, undeveloped or natural condition
    2. add areas relatively undeveloped and restorable
    3. map rare species distributions and add imperiled species
    4. select clusters or constellations of rare species and community types
    5. add unprotected and under-protected vegetation types and centers of species richness
    6. determine core protected areas and linkages, add corridors and buffer zones
G. Components:
    1. core protected areas
    2. buffer (multiple-use) zones
    3. connectivity / linkages as habitat, for seasonal movement, dispersal, and range-shifts
H. Size:
    1. Protected areas and population viability
    2. Protected areas and disturbance regimes

(Compiled from Noss 1994)

The triad approach is basically a model for characterizing the continuum of land-uses from 1) intensive commodity production areas, to 2) areas with little or no resource use by people, and to 3) areas where modest resource use compatible with ecological values occurs (Hunter and Calhoun 1993). It explicitly recognizes that all three levels

of land-use are valid and it includes protected areas and buffer zones as critical components of a larger ecologically sustainable landscape. Considerations for integrating protected areas with broader landscape context have been widely discussed (Forman 1990; Hannson and Angelstam 1991; Nelson 1991; Shafer 1990; Wilcove et al. 1986; Diamond 1986; Pickett et al. 1992).

The coarse-filter approach is based on the idea that biological diversity will be maintained by protecting representative ecosystems or physical diversity. Canada's and Nova Scotia's initiatives to protect representative natural regions are both coarse-filter approaches. A gap analysis methodology developed by World Wildlife Fund (Canada) to assess progress in these initiatives describes a systematic coarse-filter approach based on representing "enduring" or physical features at various scales from ecoregions to soil landscapes (Iacobelli et al.). Other coarse-filter approaches focus on biological communities and utilize gap analysis to identify typical communities not yet represented, as well as rare ecosystems and "hot spots" of species richness and diversity (Scott et al. 1993).

One serious shortcoming is that the coarse-filter approach does not fully protect biodiversity. Although samples of biodiversity may be captured within representative protected areas, the boundaries are not necessarily congruent with the habitat requirements of viable populations or other ecological processes. This deficiency in the coarse-filter approach may be addressed through application of a "fine-filter" layer of ecological integrity considerations such as natural processes, viable populations and critical area, and compatible human uses (Noss 1995). This fine-filter layer should encompass the realm of ecological considerations that have formed a large part of this paper.

Ecological considerations suggest that protected area design must be driven at least partially by species-habitat information relating to focus- or target-species. It is not feasible to conduct autecological or population viability analysis for all species, therefore it is necessary to identify target species. Target species may be vulnerable, important or keystone species, sensitive or indicator species, wide-ranging, space demanding or "umbrella" species, and/or flagship or charismatic species that garner support for protection (Hunter 1990; Noss 1991; 1995). Methods for identifying target species or species of concern are being developed and tested (Millsap et al. 1990; Herman and Scott 1992; 1994; Theberge 1995; Elderkin and Boates 1996; Beazley 1997). Once target species are identified, habitat requirements can be determined, along with opportunities for linkages with other habitat areas and populations. Subsequent assessment can help to identify important sites for protection, area requirements for boundary delineation, and important connections with broader landscape components.

Conclusion

Ecological considerations for protected area design have evolved in response to new ecological understanding and conservation goals. To maintain current levels of native biodiversity over the long-term, various criteria must be considered. Protected area system planners must ensure representation of typical, unique, and gradients of physical environments, with additional areas for rare species and communities, and "hot spots" of species richness. Protected areas must be large and connected enough to maintain viable populations of target or umbrella species over time, while encompassing ecological processes such as patch dynamics. Buffers to minimize detrimental cross-boundary effects and linkages for dispersal, migration and range shifts should be

included. Questions of protected area size and connectivity are informed by determining viable populations size and critical area requirements of target species, and ensuring enough habitat is protected to sustain viable populations over the long-term while allowing dynamics of succession and disturbance.

None of these considerations can be reduced to general design principles or models. Species and context specific information such as autecological, biogeographical, population viability and gap analyses are required. No single model or approach will be appropriate in every case. Multiple and integrated approaches that are goal and context driven are necessary. Generally, protected area system design needs to incorporate both coarse-filter (representative) and fine-filter (ecological integrity) approaches.

There remain many questions that ecological science cannot answer. Considerable uncertainty exists regarding processes beyond the normal human scale of observation. It is important to be cautious and to choose design guidelines and management thresholds that are well above ecological "minimums". Interventionist and adaptive management including on-going research and monitoring is required.

Ecological considerations illustrate the complexity of the task of maintaining biodiversity and other ecological processes, as well as the extent of land area required. It is unlikely that protected area initiatives alone will be comprehensive and extensive enough to meet the objectives. However, protected area systems are critical components and should be integrated with broader sustainable regional landscapes and land-use planning.

Social, political and economic criteria also need to be considered along with ecological ones in protected area system design. Protected areas that are not supported by or do not benefit local people and governments are at risk as land-use pressures and competition for scarce resources increase.

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NATURE CONSERVATION ON PRIVATE LAND IN NOVA SCOTIA

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Conservation of nature is vital to the maintenance of the ecological integrity and biodiversity of the Earth. At present, most nature conservation programs in Nova Scotia focus on either federal or provincial crown land. Despite this focus, about three quarters of the land area of Nova Scotia is privately owned, and contains many ecologically significant sites and features. Private land conservation is a strategy that has been used successfully throughout North America to complement traditional conservation efforts. It may offer great potential in Nova Scotia, although there are several issues that must be addressed to ensure its success. In this case study, I evaluated the attitudes of landowners in Hants County, Nova Scotia, and individuals involved personally or professionally in private land conservation across the province, in order to identify critical issues for successful private land conservation. These issues include a need for the following: data upon which to base private land conservation efforts; adequate and appropriate supporting mechanisms and infrastructure including funding and incentives, conservation tools, and institutional options; education of landowners and the general public to increase legal, political and public support for private land conservation; integrated planning and coordination of efforts; and a landowner-centered, community-based approach in all private land conservation efforts.

Keywords: nature conservation, natural heritage, private lands, landowner attitudes, Nova Scotia.

Introduction

The importance of preserving Nova Scotia's natural heritage is recognized in federal and provincial legislation, policies, conservation plans and strategies (Burnett and Hundert 1994; Canadian Society of Environmental Biologists 1987). It is also increasingly evident on the social agenda (Public Review Committee for the Proposed System for Parks and Protected Areas System 1995; Leduc and Smith 1992). In recent years, conservation professionals have come to recognize the need for alternative approaches to protecting natural heritage, including private land conservation (Canadian Environmental Advisory Council 1991; Carruthers 1989). At the federal level, the Protected Areas Vision for Canada, the Federal Government Green Plan, the Endangered Spaces Campaign of the World Wildlife Fund (Canada), and the National Biodiversity Strategy all recognize the vital role of private land conservation in natural heritage protection (Burnett and Hundert 1994; National Biodiversity Working Group 1994; Canadian Environmental Advisory Council 1992). Within Nova Scotia specifically, this recognition is apparent in the proposed Parks and Protected Areas System Plan; the Special Places Program; the Provincial Parks Policy; the Wildlife Strategy; and the Sustainable Development Strategy (Burnett and Hundert 1994; Leduc and Smith 1992; Ogilvie 1992).

Despite this recognition of the need for private land conservation in Nova Scotia, relatively little work has been done on how to successfully execute and organize private land conservation efforts, or how to encourage private landowners to improve their stewardship of the natural heritage values of their lands. In this study, I surveyed landowners in a region of Nova Scotia which has a high proportion of private land holdings and little formally protected conservation estate. In the survey, I examined the issues which need to be addressed in order to initiate and encourage private land conservation.

Rationale for the study of private land conservation

Nova Scotia's conservation goals[1] include: preserving biodiversity at genetic, species and community levels; protecting at least 12% of the province[2], and representing each of our 77 unique natural landscapes within a network of protected spaces (see figure 1). One of the key means to meeting these conservation goals is the Parks and Protected Areas Systems Plan. Although it represents an important conservation achievement, the plan will only protect 8% of the province and only 26 of the 77 natural landscapes (ecological regions), even if it is fully implemented (see figure 2). There is also a lack of repetition in its representation of natural landscapes, which makes the system more vulnerable to future loss of particular types of natural habitat.

Most significantly, the Parks and Protected Areas Systems Plan is incomplete because it only considered crown lands in its selection of candidate sites for legal protection. In Nova Scotia 74% of the land is privately owned (see figure 3). Many of the rare and endangered species, old growth forests and other features of important conservation value in the Province, are found on private lands (Leefe 1992). Private lands throughout southern Canada, including Nova Scotia, have a higher number of threatened birds and mammals and less protected space than public lands (Biodiversity Science Assessment Team 1994; Harding and McCullum 1994). Both the government and conservation groups within Nova Scotia recognize that private lands will play a vital role in filling significant "gaps" in the system plan, so as to meet conservation goals (Burnett and Hundert 1994; Leduc and Smith 1992; Smith 1996).

Scientific research and experience in protected areas planning and management point to the need for an ecosystem-based approach to nature conservation (Martinka 1992; Merrian 1993; Nelson 1993). Such an approach aims to protect ecological integrity and ecosystem health through the application of conservation biology principles (Canadian Environmental Advisory Council 1991; Rivard 1993; Slocombe 1993; Woodley et al. 1993). It aims to sustain all levels of biodiversity (Council on Environmental Quality 1981; Western 1992) and entire natural systems, cycles, patterns and processes (Biodiversity Science Assessment Team 1994; Dottavio et al. 1990; Franklin 1993; Freedman 1995; Merriam 1993; Noss and Cooperrider 1994; Slocombe 1993). An ecosystem-based approach to conservation moves away from the concept of managing protected spaces as if they are isolated islands of protection in a sea of exploited land (Beatley 1994; Harding and McCullum 1994; Holland 1993). In a province like Nova Scotia, in which much of the continuum between protected "islands" is privately owned, private lands will play a vital role in retention of the ecological integrity of the protected spaces. For example, private lands could be used to buffer a protected area from the deleterious effects of incompatible land and resource use (Biodiversity Science Assessment Team 1994; Harding and McCullum 1994). In addition, if managed appropriately, these lands can be used to extend protected areas boundaries to include adequate space for wide ranging species, or provide linkages between protected spaces to allow for migration, gene flow and normal evolutionary processes (Dottavio et al. 1990; Fiedler and Jain 1992; Grumbine 1990; Hudson 1991;

[1] Outlined in the Parks and Protected Areas Systems Plan (1996), the Provincial Parks Act (S.N.S., 1988, c. 18), the Wildlife Act (S.N.S 1989, c.504, s.19), the Sustainable Development Strategy for Nova Scotia (1992), the National Biodiversity Strategy, the Endangered Spaces Campaign (World Wildlife Fund Canada), and the Parks and Protected Areas Vision for Canada.

[2] Adopted from the Brundtland Commission Report, "Our Common Future," (World Commission on Environment and Development 1987) and later the World Wildlife Fund's Endangered Spaces Campaign, the Protected Areas Vision for Canada, and the Sustainable Development Strategy for Nova Scotia.

Fig1 Natural landscapes of Nova Scotia (Nova Scotia Department of Natural Resources Draft)

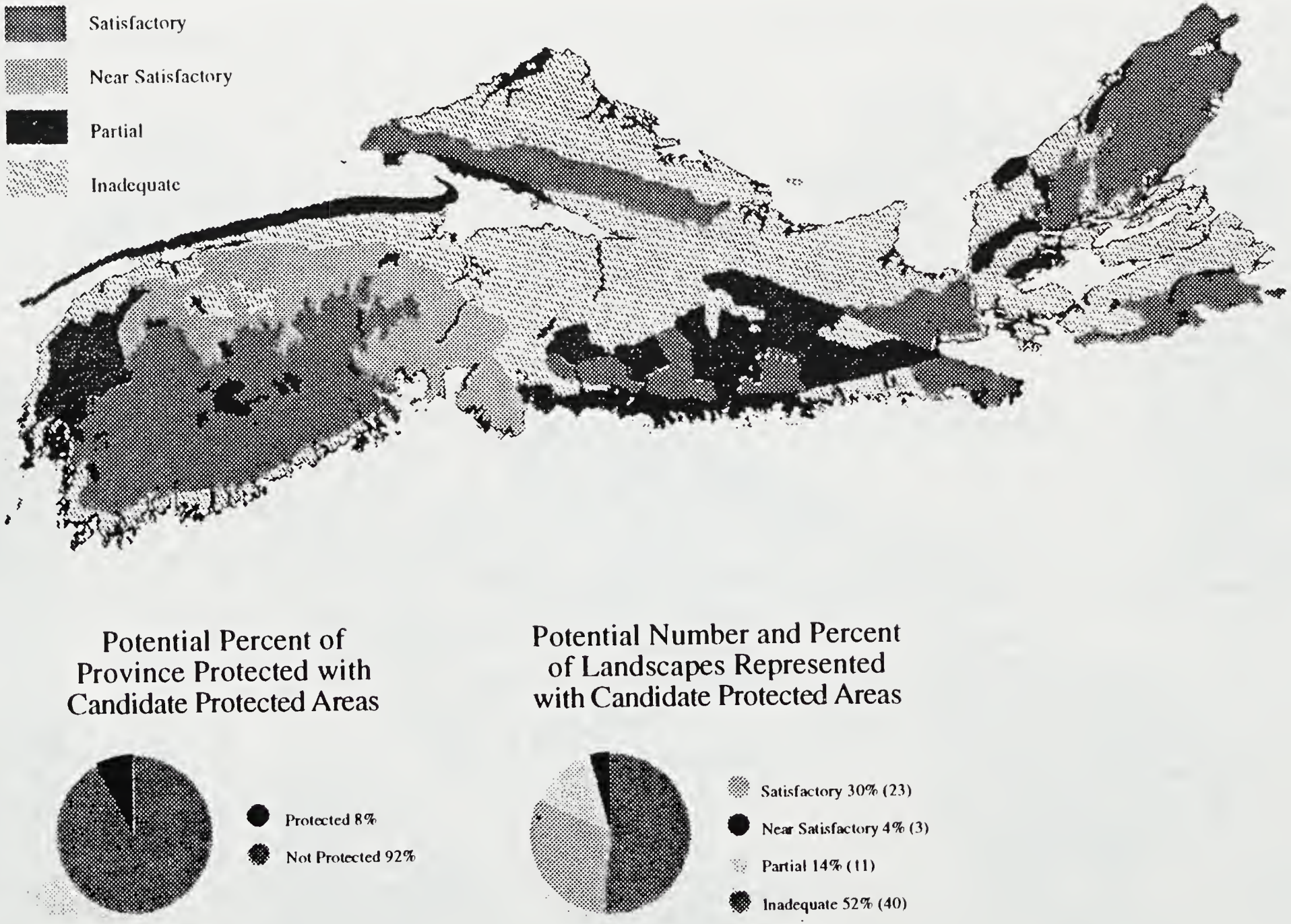

Fig 2 Potential representation with the Parks and Protected Areas Systems Plan (Nova Scotia Department of Natural Resources. March 1994. A Proposed Systems Plan For Parks And Protected Areas in Nova Scotia)

Fig 3 Land Ownership Patterns in Nova Scotia (Wildlife Advisory Council. 1993. Living With Wildlife. A Strategy For Nova Scotia)

McNamee 1989; Merriam 1993; Noss and Cooperrider 1994; Slocombe 1993; Soule and Wilcox 1980; Temple 1993).

Although used as a conservation tool in the past, public acquisition of natural areas for conservation purposes is increasingly becoming neither economically, nor politically, feasible in much of Canada (Edwards 1994; Morgan 1987). Nature conservation on private land provides a viable alternative (Deblinger and Jenkins 1991; Hilts et al. 1991; Keith 1993; President's Commission on Environmental Quality 1993). Not only does private land conservation enhance traditional nature conservation efforts by expanding and complementing the protected areas network, it may also increase public involvement in, and support for, conservation. Because it is based on education and landowner involvement in the conservation process itself, attempts to develop conservation agreements on private lands can help to instill an awareness of environmental issues, conservation values, and a sense of responsibility for protecting natural heritage (Canadian Environmental Advisory Council 1991; Filyk 1992).

Private land conservation offers a grass-roots and community-based approach to conservation (Cutting and Cocklin 1992). Such an approach is more likely to meet the needs of landowners, to be supported by the local community, and to create an atmosphere of trust and cooperation (Canadian Environmental Advisory Council 1991; Hobbs et al. 1993).

Definition of private land conservation

Private land conservation refers to those initiatives encouraging private landowners to take an active, yet voluntary, responsibility to protect the natural heritage of their land. Private land conservation includes many variations on ownership, use, and responsibility for the management and long term protection of the land. The methods range from a focus on wise use of resources, to strict preservation of an area with the assistance of an organization dedicated to conservation.

Stewardship programs encourage voluntary landowner participation through education, provision of support services and communication networks for landowners. Various options, or tools[3],may be provided for landowners to protect their lands. Such private land conservation efforts may be initiated either by government or non-government groups, or by a coalition of several interests.

Other means of ensuring the conservation of nature on private lands include involuntary approaches, such as public acquisition and management, economic controls, and land use planning (Board on Environmental Studies and Toxicology and Commission of Life Sciences 1993; Evans 1992; Hilts and McLellan 1984; Hilts 1989; Madsen and Petterson 1987; Strong 1983). These involuntary approaches are not usually considered to be part of private land conservation.

Private Land Conservation within the Nova Scotian Context

Private land conservation has been an effective conservation strategy in North America, Britain, New Zealand and Australia (Brusnyk et al. 1990; Elfring 1989; Filyk 1992; Hilts 1993; Moull 1989). Within Nova Scotia, the organized promotion of private land conservation has only begun recently. The Parks and Recreation Division

[3] Conservation tools include written agreements, conservation easements which ensure permanent protection of the land, provincial designation as a special place, and various options for donating or selling land for conservation purposes

of the Department of Natural Resources manages the Special Places Program through which private land may be designated as an ecological reserve. The Wildlife Division has initiated a wetland stewardship program for corporate owners of private land. Several non-government groups, including the Nature Conservancy of Canada, the Nova Scotia Nature Trust and regional conservation groups (the Bras D'Or Preservation Foundation, the Kingsburg Coastal Conservancy, the Tusket River Environmental Protection Association, and the Margaree Environmental Association) have become involved in private land conservation efforts. In 1992, the provincial government enacted the Conservation Easements Act (S.N.S., 1992, c. 2), which provides conservation agencies and designated non-government groups with a powerful legal tool to help landowners protect their provincially-significant lands in perpetuity. As a result of these various initiatives, private individuals and corporations have been involved in protecting natural areas through partnerships with conservation organizations and agencies, as well as through the sale or donation of land.

Enhancing Nature Conservation on Private Land in Nova Scotia

Although conservation initiatives from across North America and Britain provide a base of information about private land conservation, the associated literature strongly recommends context-specific research to determine specific issues influencing the potential success of private land conservation efforts (for references, see Sutherland 1996). These influences varied significantly among studies, across geographic and cultural lines. Little relevant research had been conducted in Nova Scotia[4]. In response to this research need, I conducted a study to examine how private land conservation could be enhanced within Nova Scotia (Sutherland 1996).

Methods

To examine the potential issues influencing private land conservation within the Nova Scotian context, I conducted a case study based in Hants County. I collected the data for the study using written questionnaires and personal interviews. Data were collected from three groups: (a) a representative randomly-selected sample of 64 rural Hants County landowners with lands of potential conservation value (there was 90% statistical confidence that the sample group was representative of the entire landowner population); (b) the entire set of 15 landowners in Nova Scotia who have some involvement in formal private land conservation efforts; (c) 39 individuals selected from government agencies, non-government groups, and academic institutions with an interest in private land conservation. The questionnaires were extensive, including 130 questions for landowners, and 175 for other respondents. Respondents took between 1 and 3 hours to complete the questionnaire.

The survey examined landowner attitudes, knowledge of nature conservation, and knowledge of private land conservation. It assessed all respondents' perspectives on potential incentives and disincentives for landowners to participate in private land conservation efforts, as well as obstacles to, and recommendations for, enhancing the success of private land conservation efforts. I presented the results using descriptive

[4] The only relevant research includes a wetland stewardship strategy (MacDonald 1990), a report on enhancing wetland stewardship using municipal planning strategies (Evans 1992) , an article on Conservation Easements (Power 1995), and some works in progress by the Nova Scotia Department of Natural Resources.

statistics, and analyzed them using measures of association and correlation, to test for patterns in responses, and differences between sub-groups of respondents (for details, see Sutherland, 1996).

Results and Discussion

General Survey Findings. The study results indicate a high level of landowner concern about the environment and support for nature conservation, including private land conservation efforts. Over 80% of landowners surveyed expressed an interest in participation in private land conservation efforts. The results, however, also suggest that several factors inhibit such participation and may influence the effectiveness of private land conservation efforts.

One of the most important obstacles to successful private land conservation within Nova Scotia is a lack of adequate data on private lands upon which to base conservation efforts and planning, including establishing priority sites. The provincial Department of Natural Resources has undertaken an extensive study of ecologically significant sites on crown lands in the province (Mackinnon 1996), and is beginning to document some sites of conservation interest on private lands. In addition to this work, it will be important to gather local knowledge about sites retaining natural values worth protecting, through community-based networks and other relatively informal initiatives.

The second major obstacle to effective conservation suggested by the study is a lack of adequate infrastructure and mechanisms in support of private land conservation. The study suggests that this inadequacy is due both to the short history of formal private land conservation efforts, as well as a lack of adequate political will (expressed as lack of social, economic and legal support for private land conservation). The inadequate economic infrastructure has resulted in a lack of funding for private land conservation initiatives. Suggested solutions which arose from the study include the development of partnerships between government and private conservation groups, and creative fund-raising efforts by the private sector. The weak economic infrastructure also means a lack of incentives for participating landowners. Incentives were strongly advocated by respondents, in light of the economic hardship facing many landowners, dependence on land and resources for economic security, and frustration by landowners about the tax penalties for donating land for conservation. The most important incentives were considered to be property and tax incentives, based on revisions to the Provincial Assessment Act and the Federal Income Tax Act. Another recommended incentive is cost-sharing to help landowners cover additional expenses of conservation, such as property surveys and appraisals needed for some conservation agreements.

As well as lack of incentives, there is currently a lack of readily available and standardized conservation "tools". These tools should be "landowner-friendly", accessible and efficient. They should be supported by documents written with landowners in mind, as well as by the relatively cumbersome technical documents which are necessary for administrative and legal purposes.

The results suggest that there is a lack of adequate and appropriate institutional options to support interested landowners. There is a need for a variety of institutions (Trusts, Foundations, etc.), ranging from local to national in scale. Of particular importance are local non-government community-based groups, whom landowners feel they can trust and with whom they can relate. Because of the limited resources available in the province for non-government groups, there are significant challenges

in securing funding, technical resources, and expertise. In response to these challenges, respondents suggested that it is important for groups to cooperate and provide mutual support and sharing of resources and expertise.

The results emphasize the need for coordination and integration of private land conservation efforts at various levels. First, on an institutional level, programs and initiatives must be coordinated between and within government agencies, between government and non-government groups, and between the various non-government groups. Second, coordination between different types of private land conservation efforts (such as resource-conservation and preservation efforts), and different approaches to protecting nature on private land (such as land use planning tools and corporate stewardship) would ensure the attainment of common goals while avoiding competition and redundancy. Finally, hierarchical integration of efforts on various scales, such as through a provincial strategy and network, would ensure adequate representation of significant local, regional and provincial ecological areas and features in a comprehensive conservation system.

A landowner-centered approach is essential for successful private land conservation efforts, including opportunities for genuine landowner involvement and consultation in all aspects of private land conservation. There should be regular communication with interested landowners. These efforts should be founded on respect for landowners, as well as respect for their knowledge and experience of the land, and recognition of their contributions.

Some responses differed significantly among the rural landowners, the landowners involved in private land conservation, and individuals offering an administrative/planning perspective. These differences point to the need for careful consideration of all three perspectives in designing and carrying out private land conservation programs and services. The random sample of landowners, for example, expressed concerns about infringements on their rights and independence as landowners, liability and trespass issues, and concerns about family inheritance and future use of the land. They demonstrated some attitudes that could work against conservation, and a need for education about basic nature conservation values and issues, as well as private land conservation options. The landowners involved in private land conservation were significantly different in their personal and land characteristics, as well as their concerns and interests. They were more likely to have higher levels of education and income, to be in non-resource-based occupations, to have an urban background, and to be only seasonal or even absentee landowners. Their needs focused more on information about various conservation options and the tax implications of each. As a result, the educational approaches appropriate for these two groups vary significantly.

The respondents stressed that private land conservation efforts must be community-based or at least include participation and support by local community groups. Existing communications and support networks provide a valuable means of conveying private land conservation messages.

Finally, the study highlights the vital role of education in enhancing private land conservation within Nova Scotia. There is a lack of landowner knowledge about nature conservation and private land conservation options, and there are some attitudes based in misunderstandings which may work against conservation. Specific landowner concerns also need to be addressed within an education framework. Such education should include information about the natural value of the landowner's property, and options for protecting it. There is also a need for general public education about the

importance of both nature conservation and private land conservation in Nova Scotia. Such education is essential in increasing the level of government and public commitment to private land conservation, through economic, legislative, and political support.

Research Needs. There is a need for further research on appropriate and relevant strategies for providing education about private land conservation for rural landowners in Nova Scotia. The Nova Scotia Nature Trust (Halifax) has taken the first steps towards addressng this need. They are currently implementing the first landowner contact/education program in the province (McLaren, personal communication), based on the study results reported here. Further efforts to field test, and modify, the study recommendations for other areas of the province are also important. At the same time, alternative approaches to protecting nature on private lands should be explored, such as corporate stewardship, regional development projects, watershed planning, integrated resource management and land use planning. Further research on the economic rationale for private land conservation is needed in order to secure public funds for private land conservation efforts. Although there may be little private land conservation professionals can do to address the broader socio-economic, policy and land/resource use issues impacting private land conservation efforts, the connections between these issues and private land conservation should be explored further. Such research might provide recommended actions to mitigate undesirable impacts and to enhance positive influences on private land conservation.

Conclusion

With conscientious effort and cooperative spirit, together with recognition of the issues identified in this research, private land conservation has immense potential in Nova Scotia. Cooperation among conservation professionals, landowners and other interested individuals will lead to sensitivity to local needs, and is more likely to be supported by a broad range of Nova Scotians than purely government-driven processes. The educational and hands-on approach of private land conservation also provides an important opportunity to develop a conservation ethic in our communities. In this way there will be growing recognition of the importance of nature, the impacts of our actions on its sustainability, and our role as stewards of the natural world, including our extensive and ecologically valuable private lands.

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LICHENS OF BEAVER BROOK, NOVA SCOTIA

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Thirty-three lichen species were collected from a woodland in Colchester County, Nova Scotia. Several 'old growth forest' lichens were identified indicating the value of further lichen studies in Nova Scotian woodlands.

Key words: lichens, old growth forests.

Introduction

Rather few lichenologists have studied the lichens of Nova Scotia. In the 1950s, a local teacher encouraged the study of lichens (Erskine, 1957) and in the same decade, MacKenzie Lamb (1954) surveyed the lichens of Cape Breton. A more recent list is included by David Lawley in his guide to the Cabot Trail (Lawley, 1995). An early study of the lichens in Halifax was published by Ward (1968) and Wolfgang Maas has examined lichens in the province for many years (Maas & Richardson, 1994). There are no comprehensive keys to the lichens of Nova Scotia, but that provided in the publication on the Lichens of the Fundy National Park in New Brunswick is extremely useful in helping to identify specimens (Gowan & Brodo, 1988).

Study Area

The area surveyed is located in Beaver Brook, Colchester County, Nova Scotia (45° 17'30"N, 63° 25'00"W). It is within the New England Section of Eastern Hemlock-White Pine-Northern Hardwoods Forest Region (Braun, 1950) and is analogous to the Acadian Forest Region (Rowe, 1972). The dominant climax tree species are representative of a more southerly floral element and include red spruce (*Picea rubens* Sarg.), eastern hemlock (*Tsuga canadensis* (L.) Carr), sugar maple (*Acer saccharum* Marsh.), American beech (*Fagus gradifolia* Ehrh.), and yellow birch (*Betula alleghaniensis* Britt.). Some sites are occupied by species of the more northerly boreal floral element and these are increasing in abundance as a result of man's activities over the forested landscape.

The study site is characterized by a cool, humid climate - a modified continental climate, the result of interactions between continental and maritime air masses. The prevailing winds are westerly. Winters are cold with frequent snowfall; springs are late, cool and wet, and summers are cool and humid with moderate precipitation and frequent fog. Topographically, the site is part of a gently undulating to rolling till plain with well to imperfectly drained loamy to clay-loamy soils derived from soft red Triassic sandstones, limestones and gypsum.

The collection area includes a well drained, moderately-steep slope covered with climax deciduous forests and an imperfectly drained flat area with an admixture of climax deciduous and coniferous forests. A variety of age classes exists within these forests, ranging from 30 to 125 years of age. Elevation ranges between 75 to 90 meters. The aspect of the site is northwest.

Lichens were collected (Richardson & Seaward) from the various trees in April, 1993 and subsequently identified.

The Lichen List

Anaptychia palmatula (Michaux) Vainio on sugar maple and yellow birch (Herb.MRDS 107461)
Bryoria sp.
Candelaria concolor (Dickson) B. Stein
Cladonia caespiticia (Pers.) Florke on spruce stump (one of the northernmost records in North America - T. Ahti in litt.) (Herb.MRDS 106524)
Collema furfuraceum (Arnold) Du Rietz
Graphis scripta (L.) Ach. on yellow birch and hemlock (Herb.MRDS 106518)
Heterodermia galactophylla (Tuck.) Culb. on sugar maple (Herb.MRDS 106672)
Lecanora carpinea (L.) Vainio on red maple
L. chlarotera Nyl. agg. on sugar maple
Lecidella elaeochroma (Ach.) M. Choisy
Leptogium laceroides (B. de Lesd.) P. Jorg. on sugar maple (det. P.M. Jorgensen) (Herb.MRDS 106678)
Lobaria pulmonaria (L.) Hoffm. on white ash (Herb.MRDS 106510)
L. scrobiculata (Scop.) DC. on sugar maple & white ash (Herb.MRDS 106592)
Lopadium disciforme (Flotow) Kullhem on yellow birch & hemlock (det. B.J. Coppins) (Herb.E; MRDS 106517)
Loxospora cismonica (Beltram.) Hafellner on hemlock (det. B.J. Coppins) (Herb.E; MRDS 106515)
Nephroma parile (Ach.) Ach.
Normandina pulchella (Borrer) Nyl. on sugar maple
Ochrolechia trochophora on balsam fir &/or hemlock (det. B.J. Coppins) (Herb.MRDS 106520)
Pannaria sp. on sugar maple
Parmelia squarrosa Hale on yellow birch & sugar maple (Herb.MRDS 106590, 107229)
Parmeliella cf. *triptophylla* (Ach.) Mull. Arg. on hemlock
Parmotrema chinense (Osbeck) Hale & Ahti
Pertusaria amara (Ach.) Nyl.
P. sp. K + brown-red, KC -, Pd + red on balsam fir
Phlyctis argena (Sprengel) Flotow
Physconia detersa (Nyl.) Poelt (det. R. Moberg) (Herb.MRDS 106673)
Platismatia glauca (L.) Culb. & C. Culb.
Pseudocyphellaria crocata (L.) Vainio
Ramalina americana Hale on yellow birch (Herb.MRDS 107228)
Thelotrema lepadinum (Ach.) Ach.
Trypthelium virens Tuck. ex Michen. on birch (det. B.J. Coppins) (Herb.E; MRDS 106516)
Usnea cf. *florida* (L.) Weber ex Wigg. on red maple
U. trichodea Ach. on yellow birch (Herb.MRDS 107462)

Discussion

The lichen flora of this woodland included a number of interesting old growth forest species including genera such a *Lobaria*, *Pannaria* and *Normandina*. Of special note is *Ochrolechia trochophora* which may be new to North America. The flora is probably typical of older regrowth forest in mainland Nova Scotia. The list from this brief survey reveals a reasonable diversity. Further studies on this type of woodland, as well as on old growth forest areas like Abrahams Lake, would be very worthwhile.

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WINTER DISTRIBUTION OF THE COMMON LOON (*Gavia immer*) AND RED-THROATED LOON (*Gavia stellata*) IN THE BAY OF FUNDY

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Common Loons (*Gavia immer*) and Red-throated Loons (*Gavia stellata*) are shown to overwinter along the coastal zone of the Bay of Fundy. The Christmas Bird Count, a volunteer monitoring survey, was used to trace 30 year trends in Common Loon population distribution and abundance. The population of Common Loons along the Nova Scotia shore appeared stable though variable while the New Brunswick population appeared to be increasing. There is an indication that the change in numbers reflects a true increase in abundance of over wintering Common Loons within the Bay of Fundy and not simply a change in distribution.

Introduction

Fundy National Park (NP), New Brunswick, Canada was established in 1948 and in the same year loons were recorded on some of the first Bird Sighting Cards of the park. These observations were along the coast of the Bay of Fundy at Herring Cove. The first recorded observation of Common Loons (*Gavia immer*) in the park on fresh water occurred in 1965 at Wolfe Lake, a small (22 ha) oligotrophic lake 14.5 km inland. Only irregular sightings were recorded until the first pair, and later juvenile, were observed on Wolfe Lake in 1976. Intermittent sightings occurred for the next decade. Confirmed nesting has taken place every year since 1989 (Clay and Clay, 1997). Common Loons are reported occasionally on other park lakes but none has become resident.

The focus of this investigation was to understand the likely movement of the Common Loons that had taken up residence in Fundy NP and determine if the presence of the newly established loons was due to an increasing population in eastern North America or the reduced recreational use of Wolfe Lake since the end of the brook trout (*Salvelinus fontinalis*) stocking program in 1980. Most smaller protected areas, such as Fundy NP, are not sufficiently large to protect an entire ecosystem, especially of migratory species such as loons. To accommodate this deficiency, the concept of ecosystem management beyond the boundaries of the national park has been adopted. This is a very plastic concept that can vary by species and thus the Greater Fundy Ecosystem for the Common Loons breeding within the park would include the Bay of Fundy shores (Figure 1).

Loons are considered an indicator of 'wilderness quality' in northern freshwater lakes in Canada and the northern USA. Despite this association with interior lakes they are sea-birds for their first 2 to 3 years (as juveniles (McIntyre, 1986)) and later, as mature adults, for more than half the year. Where individuals go when they leave their summer breeding sites is still a subject of conjecture, however they are known to over-winter along both the Atlantic and Pacific coasts. This study used observations from volunteer surveys to define the distribution of the Common Loon and the Red-throated Loon (*Gavia stellata*) on the nearest over-wintering grounds in the Greater Fundy Ecosystem of the Bay of Fundy.

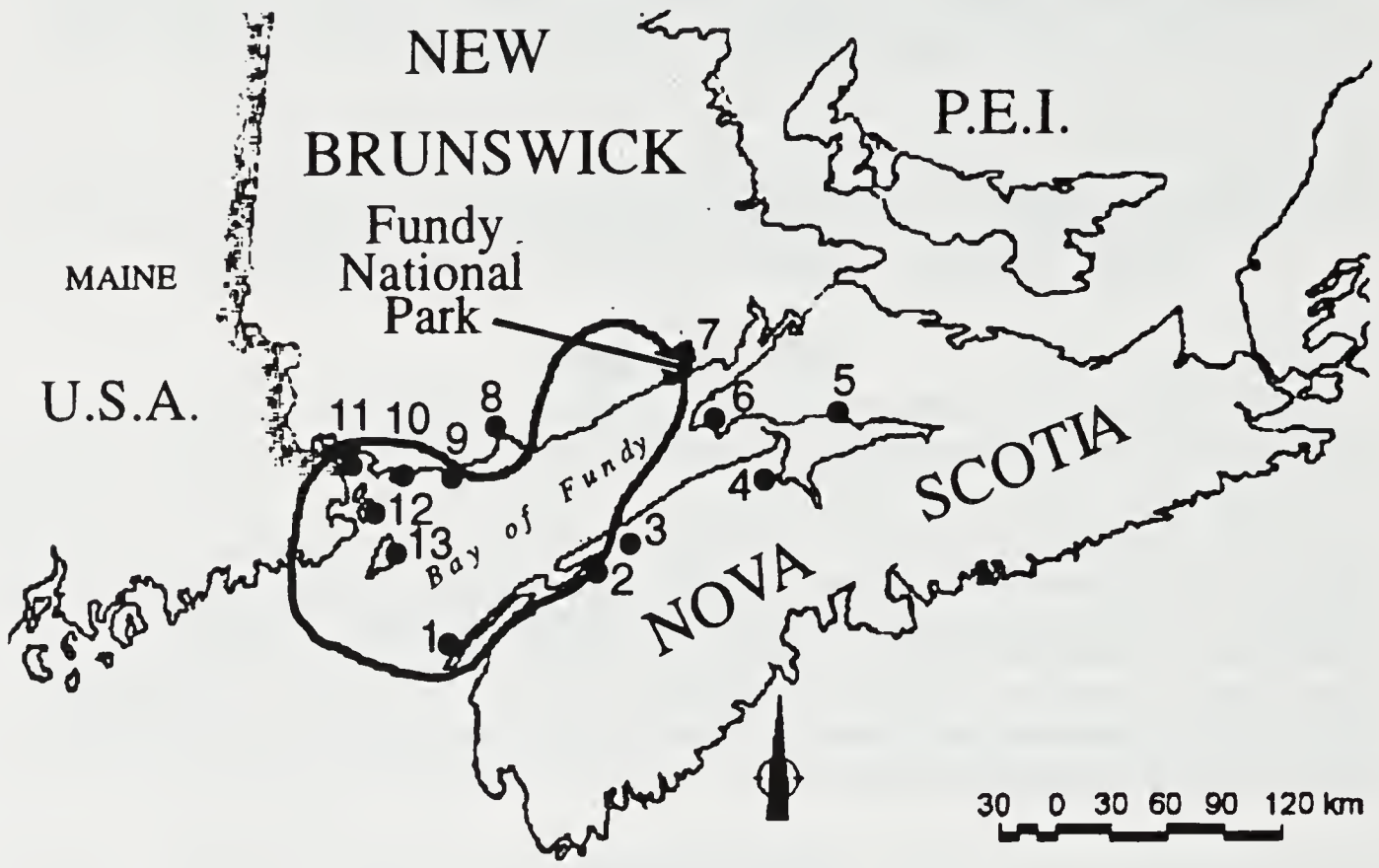

Fig 1. Bay of Fundy indicating the sites where Christmas Bird Counts have been conducted and the area considered to be the Greater Fundy Ecosystem (delineated by a solid black line) with regards the Common Loons nesting within Fundy National Park. The Christmas Bird Count survey locations, indicated by the numbers adjacent black dots are: in Nova Scotia 1 - Brier Island, 2 - Annapolis Royal, 3 - Bridgetown, 4 - Wolfville, 5 - Economy, 6 - Apple River / Advocate Harbour, and in New Brunswick 7 - Alma (Fundy National Park), 8 - Saint John, 9 - Lepreau, 10 - Blacks Harbour, 11 - St. Andrews, 12 - Campobello Island, 13 - Grand Manan Island.

Methods

Long term data sets that provide insight into loon biology, distribution, and behavior included the Bird Sighting Cards (BSC) of Fundy NP, completed by various volunteers and park employees from 1948 to 1980 and the Christmas Bird Count (CBC) data compiled by many volunteers.

The BSC are for the immediate area of Fundy NP and the adjacent coastal zone. They can be taken as an indication of presence of a species but are not a complete nor a uniform survey.

The CBC is conducted by volunteers at specific sites (Figure 1) on a more systematic basis than the BSC. These data do provide an indication of the presence, absence and relative abundance at the end of December. Although year to year variation is expected at a site, the combined data of 5 or more sites on each side of the Bay of Fundy over nearly 30 years (since 1960 for New Brunswick shore and 1965 for Nova Scotia shore) are believed to provide a true indication of trends in the loon populations.

Results

The BSC of Fundy NP, though incomplete in their coverage, provide an overview of the seasonal use of the marine environment along the coast adjacent to Fundy NP. This

distribution of coastal sightings of Common Loons (Figure 2) indicates continuous use of this coastal zone from April to early November with 2 sightings in early December. The BSC record a large offshore migration of Common Loons on 25 and 26 April, 1980, this occurred at the time when birds were moving inland to freshwater lakes. These and other inland sightings were not included in the data used in Figure 2.

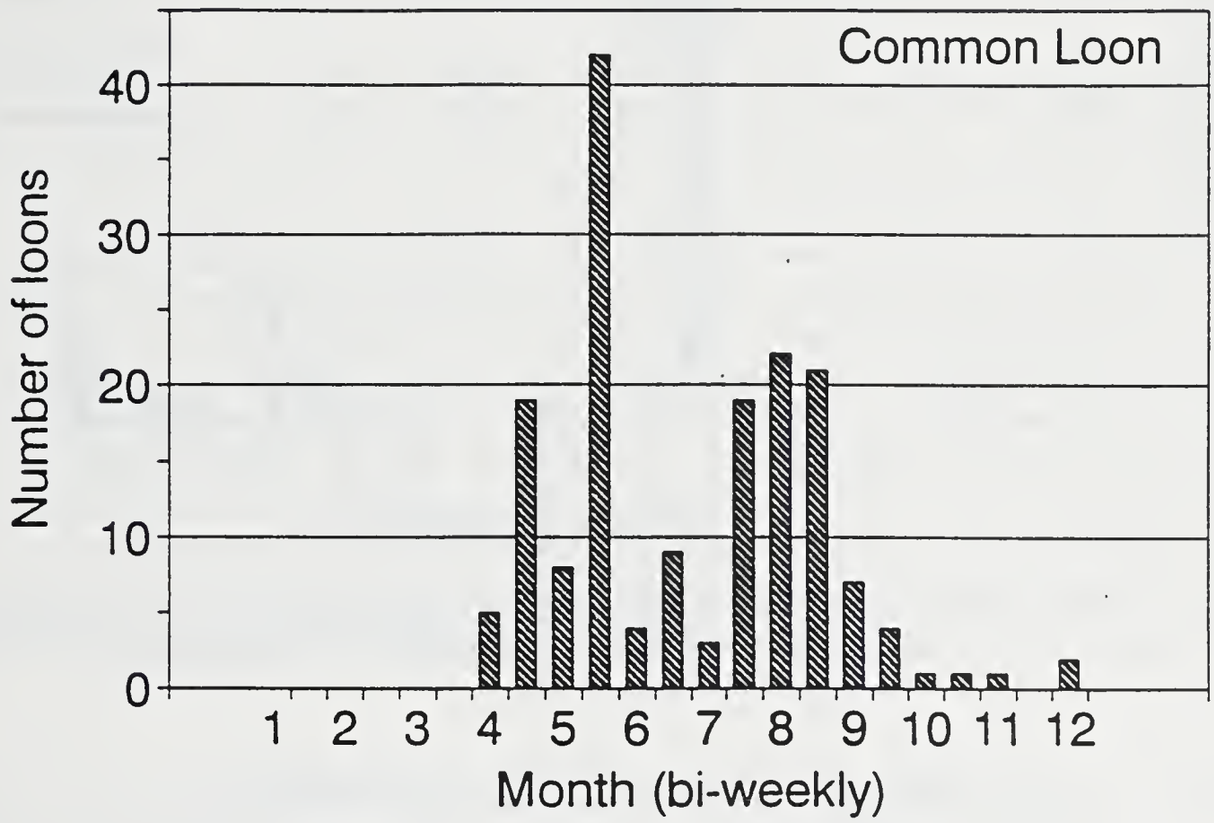

Fig 2. Common Loons reported on Bird Sighting Cards from Fundy National Park coastal zone. All years 1948 to 1980 are combined by 2 week periods.

The Red-throated Loon exhibits a different distribution from the Common Loon. They are more frequently observed in the autumn and winter (Figure 3). There were no observations of Red-throated Loons away from the coast. The large numbers in late April were probably massing for their migration north to their Arctic breeding grounds.

CBC data support the BSC records indicating a limited use of the coastline adjacent to Fundy NP by overwintering Common Loons. Over the 35 year time series, there were 5 Common Loons recorded while there were 54 Red-throated Loons.

The mean number of loons observed at each CBC site around the Bay of Fundy provides an indication of the distribution of these species in early winter (December / January). On both the north (New Brunswick) shore and the south (Nova Scotia) shore the density of Common Loons was higher towards the mouth of the bay (Tables I and II).

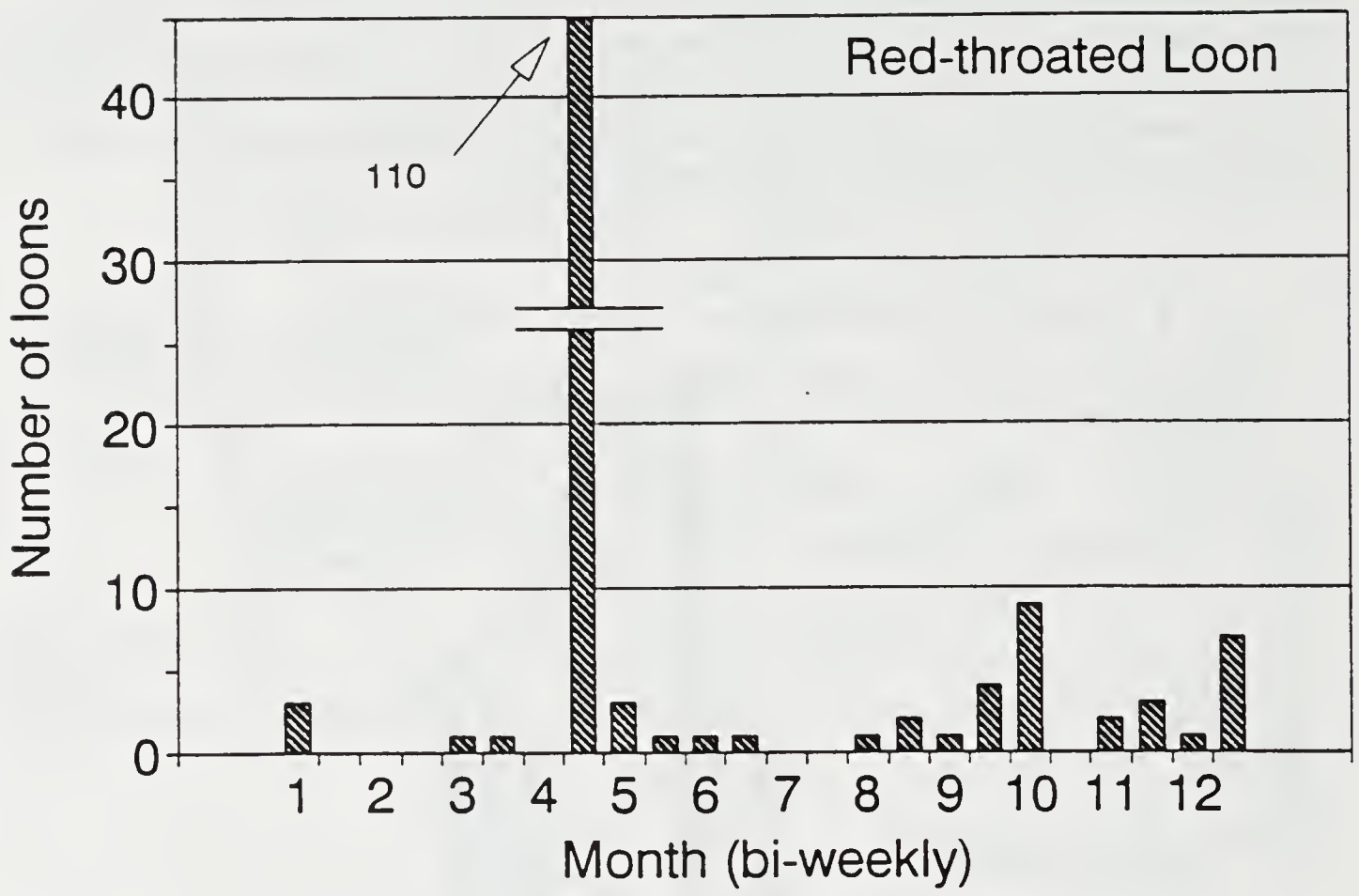

Fig 3. Red-throated Loons reported on Bird Sighting Cards from Fundy National Park coastal zone. All years 1948 to 1980 are combined by 2 week periods.

Table I. Number of Common Loons observed per 100 hours of Christmas Bird Count survey effort in 5 year time periods (e.g. 1965 is 1965 to 1969) on the New Brunswick shore of the Bay of Fundy. An asterisk indicates no survey coverage of potential loon habitat during the time period (Christie, 1996, Marys Point Shorebird Hemispheric Reserve, New Brunswick, pers. comm.).

	1965	1970	1975	1980	1985	1990	Mean
Fundy NP	0.0	0.8	0.0	1.5	0.0	0.0	0.4
Saint John	1.0	0.8	2.2	2.7	7.3	4.0	3.0
Lepreau	45.3	33.5	45.2	59.7	129.0	181.0	65.5
Blacks Hbr.	*	18.7	41.5	31.3	92.4*	113.4*	60.4
St. Andrews	6.7	23.7	20.5	27.5	81.5	146.3	36.8
Eastport-Campobello	108.0	32.1	91.8	53.7	33.0	50.8	52.5
Grand Manan	15.2	19.4	30.0	15.2	36.4	37.0	26.5

* a new organizer/compiler of the count since 1987 has increased efforts to survey the accessible shoreline.

Table II. Number of Common Loons observed per 100 hours of Christmas Bird Count survey effort in 5 year time periods (e.g. 1965 is 1965 to 1969) on the Nova Scotia shore of the Bay of Fundy. A dash indicates no survey during the time period.

	1965	1970	1975	1980	1985	1990	Mean
Economy	-	0.0	0.3	0.0	0.4	0.0	0.2
Wolfville	0.0	0.0	0.0	0.0	0.2	0.7	0.2
Apple Riv./ Advocate Hbr.	-	-	7.7	5.4	-	3.1	4.6
Bridgetown	9.5	40.0	4.9	5.5	18.2	37.1	15.8
Annapolis Royal	4.3	33.3	10.9	-	17.3	37.8	23.7
Brier Island	85.7	191.7	112.1	102.2	96.1	182.7	126.4

Reviewing the seven CBC sites on the New Brunswick shore of the Bay of Fundy (Figure 4) shows Saint John and Fundy NP provide 50% of the combined observer hours but less than 5% of the loons; therefore these two sites were dropped from the data series for the following analysis. Combining the data for the remaining five CBC sites along the New Brunswick shore of the Bay of Fundy indicates an increase in the number of Common Loons observed and an increase in the effort, the total number of observation hours (Figure 5). To identify if the increase in loon numbers is real or simply the result of increased effort we calculated the observation per unit effort (OPUE). There does appear to be a true increase in overwinter Common Loon numbers along the New Brunswick coast of the Bay of Fundy (Figure 6).

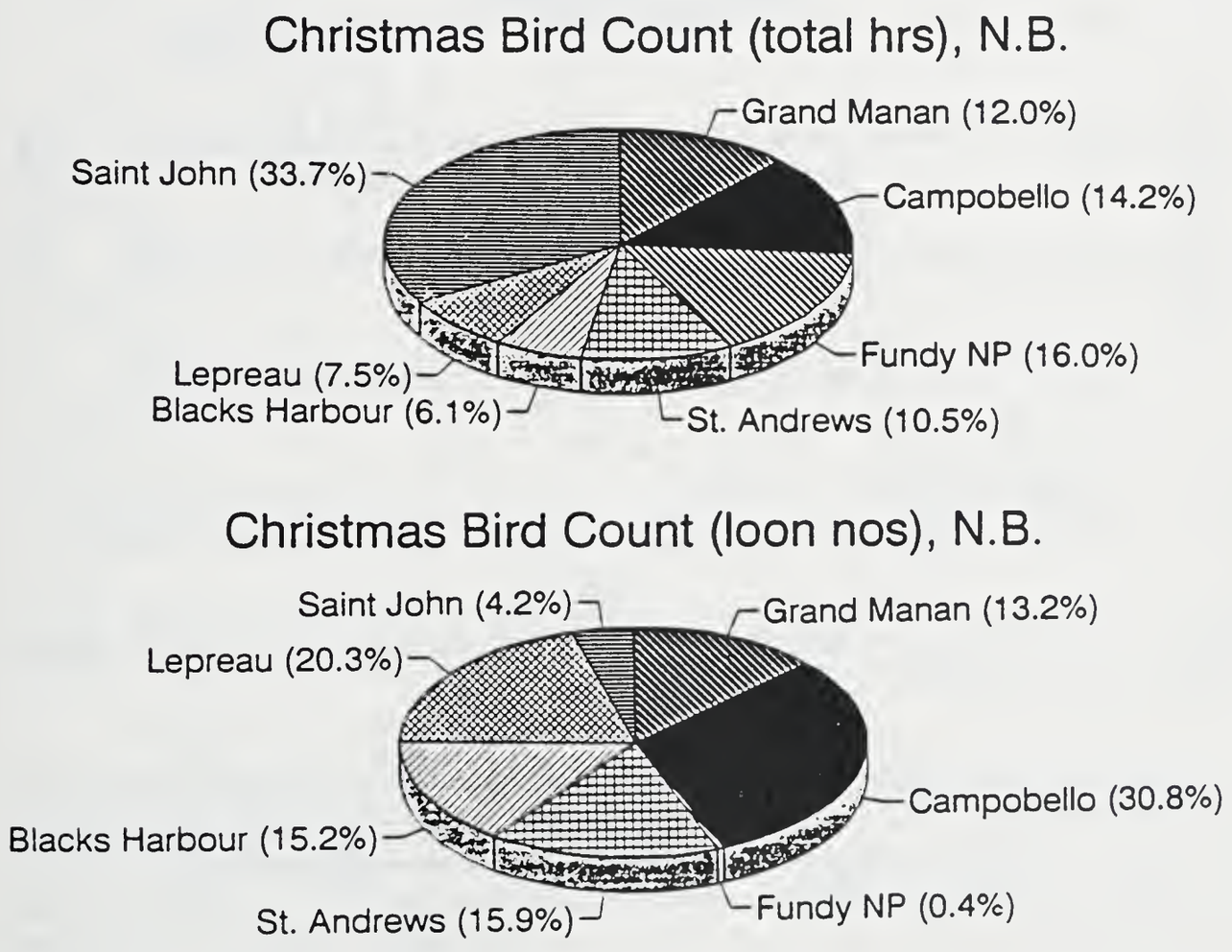

Fig 4. Christmas Bird Count data for Common Loons (numbers and effort) for 7 sites along the New Brunswick shore of the Bay of Fundy.

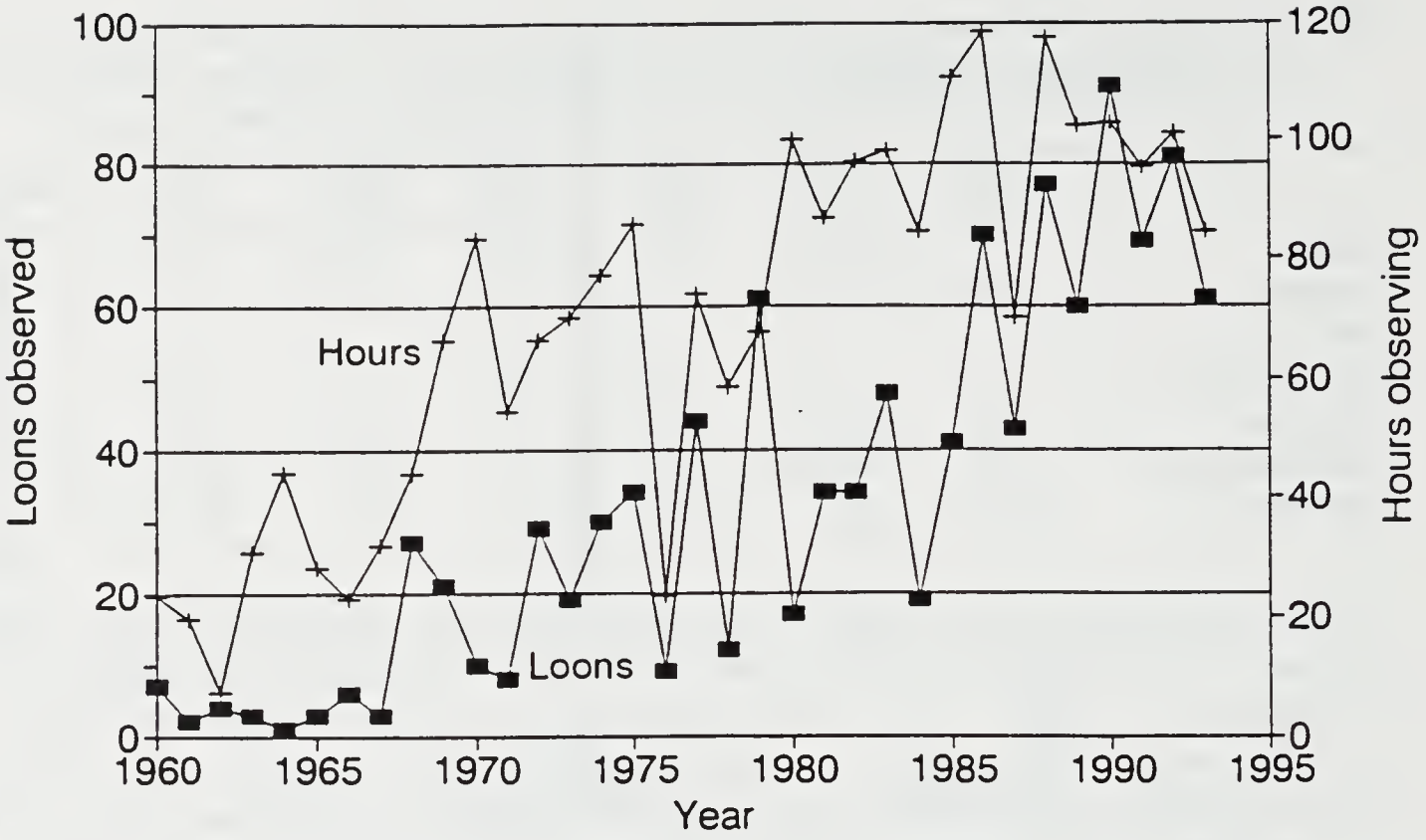

Fig 5. Common Loon Christmas Bird Count data (numbers and effort) for the 'loon areas' (see text) of the New Brunswick shore of the Bay of Fundy.

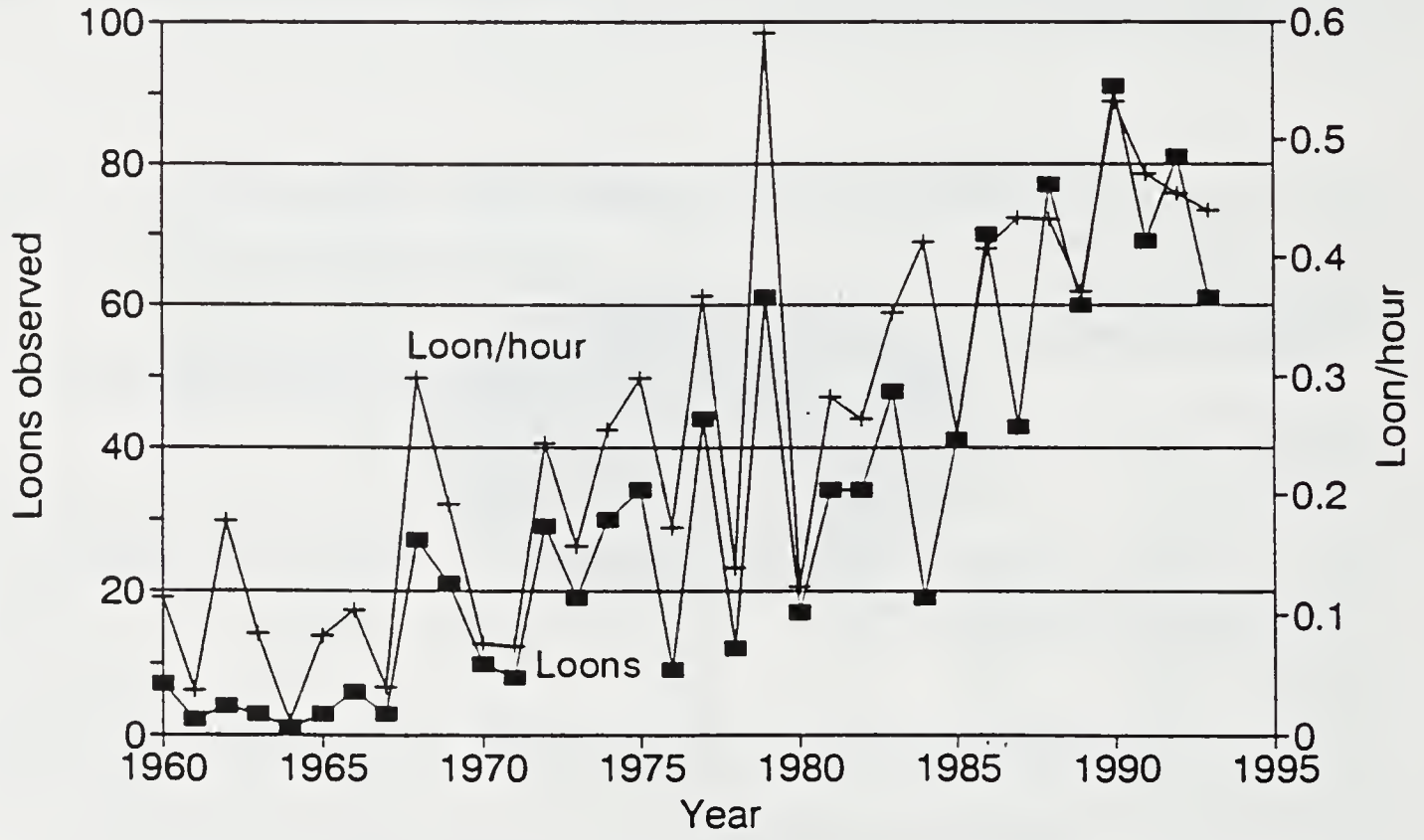

Fig 6. Observation per unit effort of Common Loons along the New Brunswick shore of the Bay of Fundy.

Using the same procedure we have investigated the loon populations along the Nova Scotia shore of the Bay of Fundy. The upper bay sites at Apple River/ Advocate Harbour, Economy, and Wolfville (Figure 7) contribute 66 % of the observation hours and 1.5 % of the Common Loons. Thus these three sites were dropped from the data series. The combined data from the remaining three sites, though highly variable do not indicate any systematic change in Common Loon populations (Figure 8 and 9).

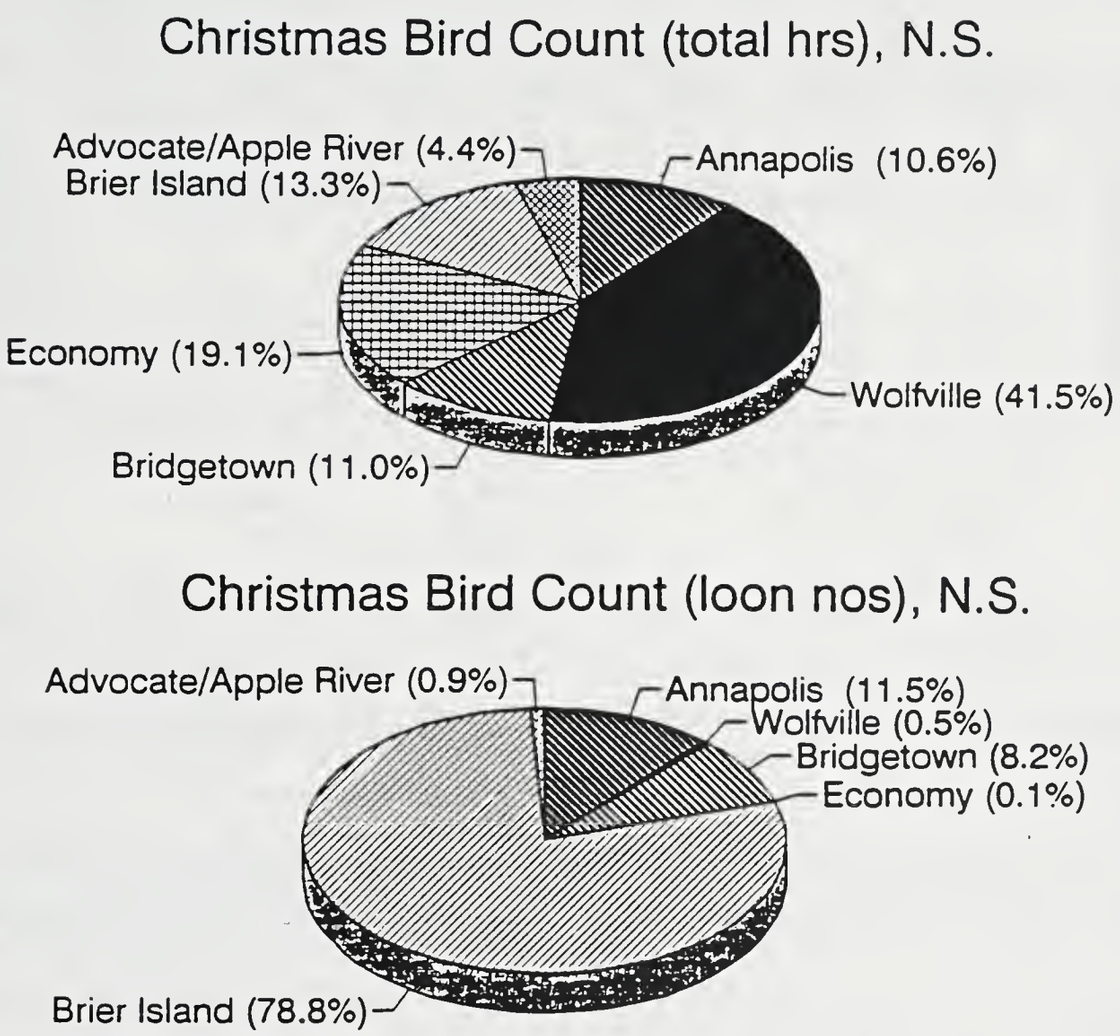

Fig 7. Christmas Bird Count data for Common Loons (numbers and effort) for 6 sites along the Nova Scotia shore of the Bay of Fundy.

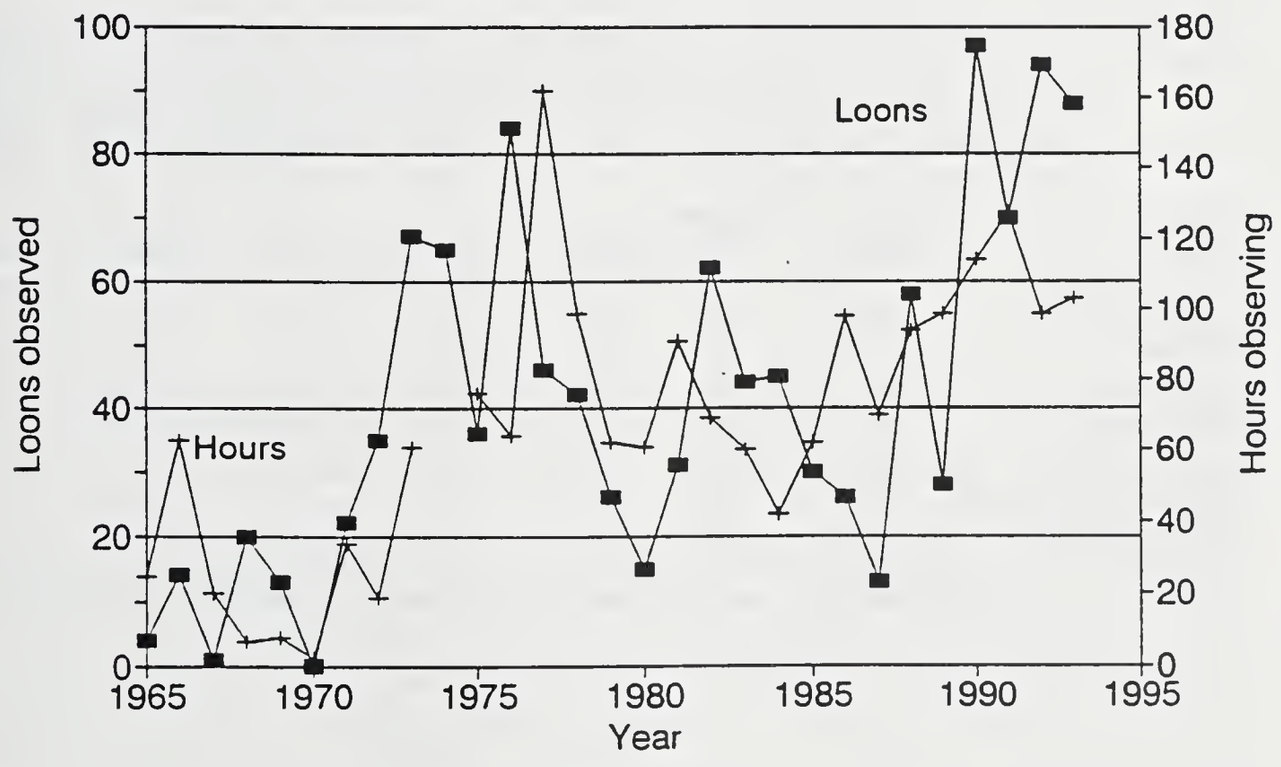

Fig 8. Common Loon Christmas Bird Count data (numbers and effort) for the 'loon areas' (see text) of the Nova Scotia shore of the Bay of Fundy.

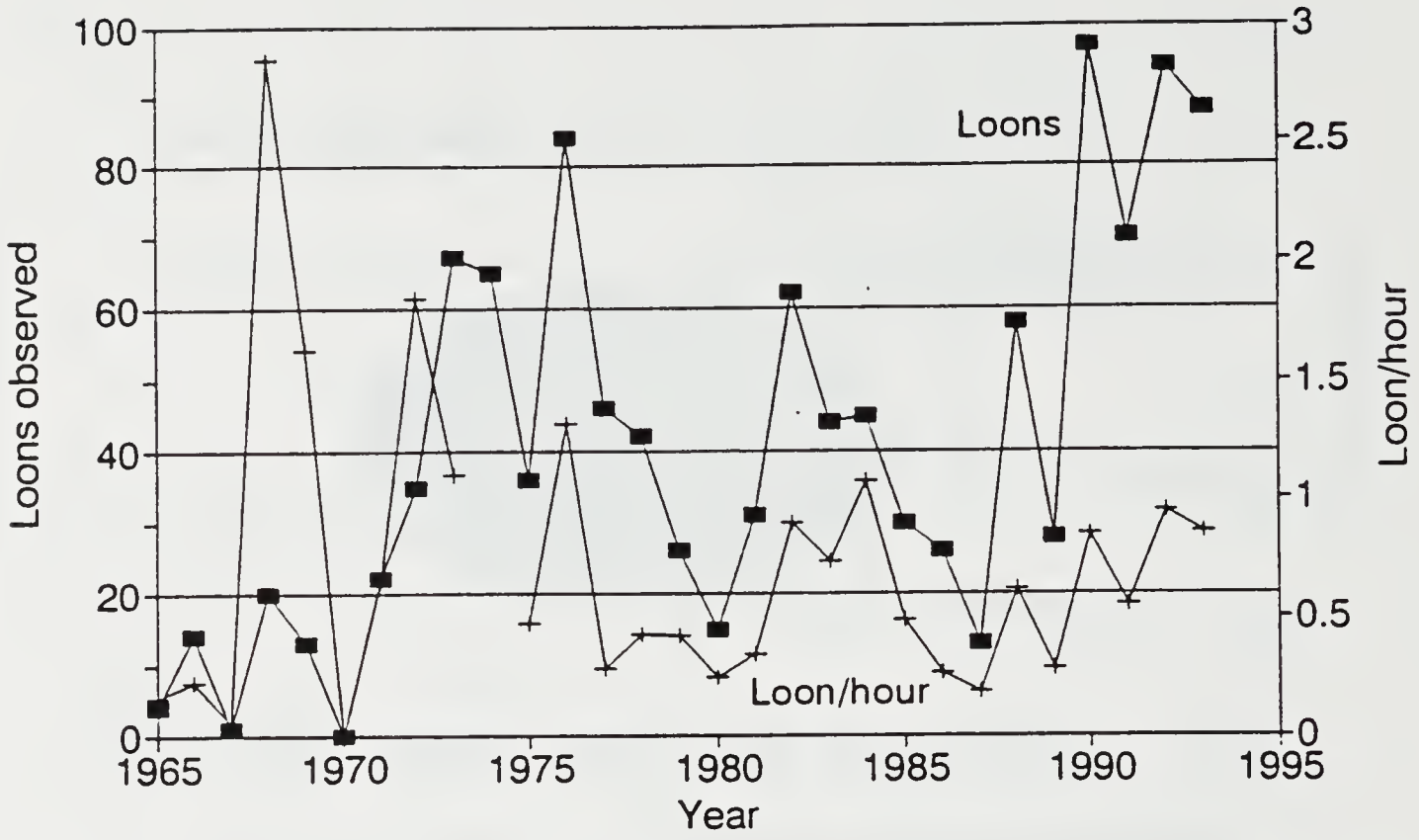

Fig 9. Observation per unit effort of Common Loons along the Nova Scotia shore of the Bay of Fundy.

The Red-throated Loon overwintering population as indicated by CBC data has been low in numbers, highly variable, and without any evident trend throughout the entire Bay of Fundy (Tables III and IV). They also appear to be more uniformly distributed during the early winter period through the bay. The population on the Nova Scotia shore has been intermittent over the past 30 years. They appear more uniformly distributed and occur in greater numbers on the New Brunswick shore than on the Nova Scotia shore of the Bay of Fundy.

Table III. Number of Red-throated Loons observed per 100 hours of Christmas Bird Count survey effort in 5 year time periods (e.g. 1965 is 1965 to 1969) on the New Brunswick shore of the Bay of Fundy. An asterisk indicates no survey coverage of potential loon habitat during the time period (Christie, 1996, Marys Point Shorebird Hemispheric Reserve, New Brunswick, pers. comm.).

	1965	1970	1975	1980	1985	1990	Mean
Fundy NP	17.6	3.1	2.0	7.0	3.1	1.6	4.2
Saint John	0.0	0.8	0.5	0.0	1.3	1.5	0.7
Lepreau	15.1	5.1	9.5	10.5	0.0	2.9	6.3
Blacks Hbr.	*	0.0	0.0	0.0	0.0*	18.9*	4.2
St. Andrews	0.0	2.0	0.0	0.0	0.0	0.0	0.4
Eastport-Campobello	0.0	7.7	1.0	5.1	1.5	11.1	4.7
Grand Manan	3.8	0.0	0.0	4.3	1.3	1.7	1.6

* a new organizer/compiler of the count since 1987 has increased efforts to survey the accessible shoreline.

Table IV. Number of Red-throated Loons observed per 100 hours of Christmas Bird Count survey effort in 5 year time periods (e.g. 1965 is 1965 to 1969) on the Nova Scotia shore of the Bay of Fundy. A dash indicates no survey during the time period.

	1965	1970	1975	1980	1985	1990	Mean
Economy	-	0.0	0.0	0.8	1.3	1.2	0.8
Wolfville	0.0	1.5	0.2	0.8	0.6	0.1	0.5
Apple Riv./ Advocate Hbr.	-	-	7.7	1.8	-	0.0	2.1
Bridgetown	0.0	16.0	0.0	0.8	0.0	0.0	1.5
Annapolis Royal	0.0	12.5	0.9	-	2.3	1.3	1.9
Brier Island	0.0	2.4	5.8	7.5	0.0	8.7	5.1

Discussion

A recent review of Common Loon mortality on marine overwintering grounds by Spitzer (1995) has identified a potential cause for unrecorded loon mortality. When the Common Loon is flightless during its winter molt period at sea it is particularly at risk from sea borne pollutants. The loon's lack of mobility increases its risk of starvation if fish populations have moved or been removed through overfishing. Any problems encountered in this critical overwinter period could have a significant effect on the Common Loon population in seemingly unrelated sites. This may also be a factor for the Red-throated Loon which moults during autumn after their return migration from the Arctic (Godfrey, 1979).

Common Loons use the marine environment adjacent to Fundy NP in April and May as a staging area before dispersal to interior lakes (Figure 2). Clay and Clay (1997) recorded the loons arriving at Wolfe Lake as the ice was breaking up at the end of April to the first week of May. Unsuccessful nesting results in Common Loons leaving freshwater lakes at the end of July to the beginning of August and forming off shore groups (Figure 2). They leave the Fundy NP coastal areas as the temperature drops in late autumn. It is believed that the Fundy NP loons are part of this congregation. Recent banding of the birds at Wolfe Lake may provide evidence for this movement in the future. Red-throated Loons, being an Arctic species and possibly more tolerant of cold water, remain along the park coastal zone until mid January (Figure 3).

An aquaculture industry has developed in many of the sheltered coastal areas of the Bay of Fundy since the early 1980's. The region between Blacks Harbour and St. Andrews is the center of this industry. Christie (1996, Marys Point Shorebird Hemispheric Reserve, New Brunswick, pers. comm.) has suggested that wild fish attracted to aquaculture cage sites would increase the available food for fish-eating birds. Over this same time period and a few years prior there has been a reduction in fish processing plant effluent in these coastal areas. This has altered the distribution of juvenile fish, particularly pollock (*Pollachius virens* L.) (Clay *et al.*, 1989), on both sides of the Bay of Fundy from the late 1970's to the mid 1980's. Both of these food sources may be factors in loon distribution, however, natural variation in marine fish populations of the area is great and would likely overshadow any changes due to scavenging.

Common Loons appear to be increasing in numbers on their overwintering range on the north shore of the Bay of Fundy while remaining relatively stable on the south shore. This trend, particularly evident since 1980 (Figure 6), could be the reason that loons are seeking nesting sites in Fundy NP. Protected areas are important for loons since

human interference (recreation) and unstable environments can deter successful nesting behaviour. Loons have not nested on other potentially suitable lakes in Fundy NP because of high recreation pressure on these lakes. It is likely that the Common Loon could expand its summer range in other lakes (e.g. Bennett Lake and possibly Tracey Lake) in Fundy NP if recreational pressure were reduced.

Acknowledgements

David Christie, N.B. Federation of Naturalists provided the New Brunswick Bay of Fundy Christmas Bird Count (CBC) Common Loon and Red-throated Loon data. The Nova Scotia Bay of Fundy CBC Common Loon and Red-throated Loon data was purchased from Nova Scotia Bird Society Sanctuary and Scholarship Trust Fund. Both of these data sets are the results of efforts by many volunteers over more than 30 years.

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SAFETY OF SEAL OIL AS A NUTRITIONAL SUPPLEMENT

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Preamble

Dr. Charles Mortimer (Bud) Harlow was born in Truro, Nova Scotia on 3 July 1908, and received his high school education at the Colchester County Academy located in that town. He attended Acadia University where he graduated with a B.Sc. in 1931, and then decided to pursue graduate studies at McGill University where he studied under the supervision of two distinguished doctors, J.B. Collip and Hans Selye. After being awarded a Doctor of Philosophy degree in 1938 by McGill, he entered medical school at that University, completing the M.D. program in 1941. During the Second World War, Dr. Harlow served as a Surgeon Lieutenant with the RCNVR and after the war continued his association with the Navy serving as a Consulting Pathologist of that service for many years. In 1950 he was appointed to the Faculty of Medicine at Dalhousie University where he taught laboratory medicine to medical students for twenty-eight years. Dr. Harlow also served as the Director of the Pathology Laboratories at Camp Hill Hospital and was a Consulting Pathologist to the Halifax Infirmary for many years.

While studying under Dr. J.B. Collip in the 1930s, Dr. Harlow became interested in the study of cholesterol in the vascular system and, when he took up his appointment at Dalhousie in the early 1950s, continued to study this important topic. Together with his colleagues he carried out research which demonstrated the value of fish in a person's diet in that it lowered cholesterol levels in the blood and therefore represented a preventative measure to reduce the incidence of heart disease.

Dr. Harlow was a popular speaker and frequently addressed groups interested in improving their health through diet. He is now retired and living in Halifax.

The 1950s and 1960s were a simpler world for lipid chemists. Modern chromatographic and spectroscopic techniques were just being introduced. Many scientists and researchers however became interested in the new idea that polyunsaturated fatty acids would reduce serum cholesterol and so improve longevity by reducing atherosclerosis. To paraphrase a remark of J. Sabine (1977), "anybody with 12 rats and a colorimeter plunged into blood lipid research." Several worked with fish oils and/or the unsaponifiables from fish oils (Peifer, 1967). Dr. C.M. Harlow had an ideal base for such research in Camp Hill Hospital (Harlow, 1961) and visited author Ackman at the Halifax Laboratory of the Fisheries Research Board of Canada to explore the concept of using fish oil in such research. At that time K. Karlsen operated a plant in Blandford, Nova Scotia for the production of seal oil from the blubber attached to seal pelts. The oil was easier to hydrogenate than many fish oils and was acceptable to the

margarine and shortening industry for hydrogenation and food use (Conacher et al., 1972; Mag, 1973). The fatty acid composition was known in some detail (Ackman et al., 1963) and after discussion it was agreed that it be used in Dr. Harlow's project.

Seal oil is made from the seal blubber. The latter is a layer of pure fat up to 5 cm in thickness. It has several physiological functions that are shared with sea lions, whales, manatees and other marine mammals. An advantage over fish oil was that the blubber sheet could be held in frozen storage until needed at Camp Hill Hospital. Then a simple procedure worked out in the author's laboratory was applied. Appropriate cubes of blubber could be cut out of the slab and any exposed surfaces trimmed clean. A cube could be dropped into a Waring Blendor™ half full of ice water, and in less than a minute the clear, virtually colourless and tasteless oil would be freed and float to the surface where it could be decanted. Since this simple procedure ensured a steady supply of very clean oil no concern existed over using antioxidants or about peroxides developing during oil storage. Dr. Harlow presented his results in public on only one occasion (Harlow et al., 1958) and the abstract from that meeting is reproduced as Figure 1. The patients under his care obviously found the freshly prepared seal oil quite acceptable, and Dr. Harlow observed no adverse effects with 26 ml of seal oil administered twice per day, to patients in his cardiac care program. After two months of dietary supplementation serum cholesterol was substantially reduced as stated in the abstract (Figure 1).

Dalhousie University
Medical Research Committee

Abstract of Clinical Research Meeting, November 13, 1957

Serum Cholesterol Research to Marine Oil in Cases of Atherosclerosis

C. M. HARLOW, LEA STEEVES and A. MYRDEN

A marked decrease in the amount of ordinary fats in the usual American or Western European diet, without any change in the amount of calories or vitamins, lowers the serum cholesterol level. The fall is rapid in the first few days, but after a few weeks there is an approach to a new plateau (Keys). Such low fat diets usually contain less cholesterol and animal proteins, but the change in the serum cholesterol level in man does not depend upon this fact (Keys and Anderson). The responsible agent is clearly either in the quality of the fats or in the ratio of fat to carbohydrate calories.

It is tempting, then, to ascribe the effect of low fat diets to the decrease in animal fat, especially since some vegetable and marine oils given in large amounts may depress the serum-cholesterol level (Kinsell) (Bronte-Stewart). It appears that the effect of dietary fats on the serum cholesterol should be related to chemical composition rather than to origin.

For the past year we have conducted at Camp Hill Hospital a small Research project in which we investigated the effect of North Atlantic seal oil on a group of patients with atherosclerosis and hypercholesterolemia.

The group included cases of ischemic heart disease and peripheral atherosclerosis with claudication. All patients were placed on a low fat diet (5%) for two weeks to one month. During that time there was a definite lowering of the cholesterol level (340 mg% to 280 mg%). The patients were then given 26 cc. of seal oil twice a day. After a further two months, the cholesterol level decreased to around 200 mg%.

It is interesting that we were able to lower the cholesterol level of 10 patients with atherosclerosis and hypercholesterolemia on a low fat diet and that a further lowering of the cholesterol could be obtained by adding 50 grams of seal oil (450 calories) to the low fat diet.

Fig 1 Reproduction of the abstract of a 1958 presentation by C.M. Harlow on the impact of high doses of seal oil on human hematology.

Part of the new interest in the effects of polyunsaturated fatty acids on cholesterol (Harlow, 1961; Sabine, 1977; Peifer, 1967) soon drifted into the intensive use of liquid vegetable oils with a high content of linoleic acid, for example corn oil (Lands, 1986). Although the more widely used soybean oil had 50-60% linoleic acid (18:2n-6), it also had 10-12% alpha-linolenic acid (18:3n-3) which was less stable and not considered "essential" by many nutritionists. The simple shorthand notation of chain length, number of ethylenic bonds and position relative to the terminal methyl group define the two basic families of polyunsaturated fatty acids. "Omega-3" now a popular descriptive term, equates with n-3. The original rat work decades ago that defined linoleic acid (n-6) as "essential" was not thought applicable to the n-3 family of fatty acids until shown to be effective in the human neural system (Holman, 1992). In fact it has taken until this decade to have alpha-linolenic acid widely recognized for a biochemically important role in human nutrition (British Nutrition Foundation, 1992), However, very recent reviews elevate it to a more appropriate importance in human health (Cunnane, 1996). A section heading in a recent review on fats and fatty acids is simply "saturates, oleic acid and linoleic acid" (Katan et al., 1994) so alpha-linolenic acid is still not unequivocally accepted as a healthy food fat component despite lengthy or detailed review articles (Descomps, et al., 1995; Léger, et al., 1995; Mendy, 1995; Combe, 1996; Renaud, 1996) especially with reference to conversion to docosahexaenoic acid (DHA or 22:6n-3), and the popular Mediterranean diet (de Lorgeril et al., 1994).

Fish oils do not generally contain more than 1% alpha-linolenic acid, but instead have a total of 10-25% of the two higher "omega-3" fatty acids eicosapentaenoic (EPA or 20:5n-3) and DHA. These accumulate in marine life as shown in Figure 2 and then pass from the food eaten by the seals into the depot fat, but this fat is organized differently on the glycerol molecules. The first person to demonstrate this effectively was H. Brockerhoff of the Fisheries Research Board of Canada working in Halifax. All of his publications are conveniently listed in the references of a 1989 book chapter by Ackman and Ratnayake (1989). The essential difference between the fatty acid distribution on triacylglycerols can be summarized for the n-3 docosahexaenoic acid (DHA or 22:6n-3) as shown in Table 1. The same concept applies to the distribution of n-3 eicosapentaenoic acid (EPA or 20:5n-3) but a little less precisely as summarized in some detail in a book on triglycerides by C. Litchfield (1972).

Table 1 Distribution of DHA on the glycerol molecules of two types of marine oils.

	Fish oils	**Seal oils**
sn-1	y = 0.28x	y = 0.94x
sn-2	y = 2.06x	y = 0.22x
sn-3	y = 0.66x	y = 1.84x

where y = mole % of 22:6 and x is the total of that fatty acid in the triacylglycerol.

This was an academic curiosity until the studies of the Danish group headed by Bang and Dyerberg on Greenland Eskimos showed that this population, subsisting largely on seal fats, did not have a high death rate from cardiovascular disease (Bang and Dyerberg, 1976; 1980; 1981; Bang et al., 1980; Dyerberg and Bang, 1978; Dyerberg et al., 1978; Ackman et al., 1980; Sinclair, 1980). Unfortunately seal oil was not available for medical research in 1970-90 and fish oil became the main vehicle for EPA

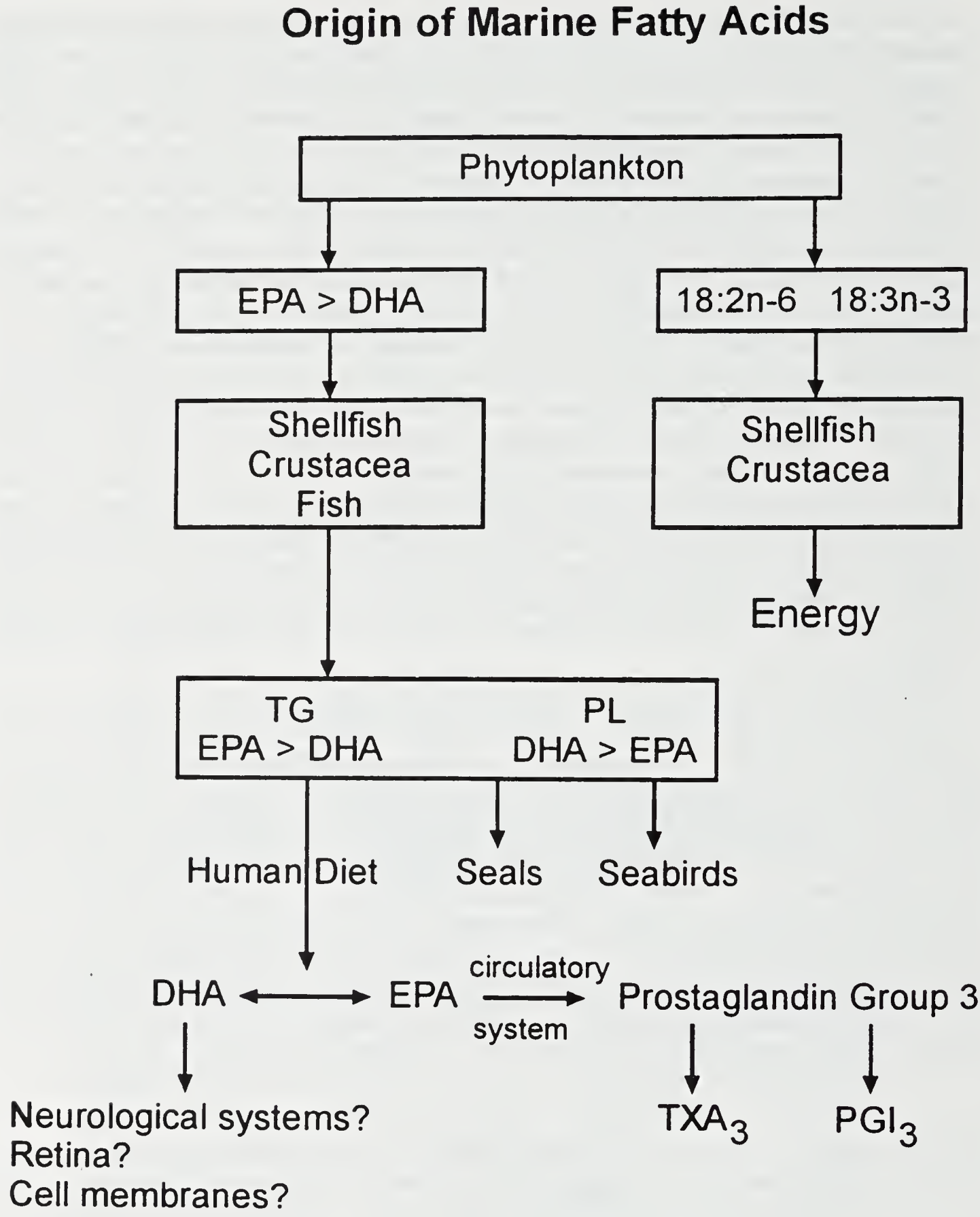

Fig 2 Outline of the utilization of different chain lengths of polyunsaturated fatty acids produced by marine phytoplankton.

and DHA research. Initially most was supplied in refined form by the company British Cod Liver Oils as MaxEPA™ (Ackman et al., 1989). It is ironic that cod liver oil was widely given to children in large doses as a vitamin source without concern for safety, or any known ill effects, for over a century. It has rapidly become clear that the safety aspects of fish oils in human clinical trials are not a problem, although unlike the situation in Dr. Harlow's era cumbersome examination of protocol procedures by committees has became the normal procedure prior to effective research. Misgivings about the safety of such products by North American regulatory agencies are difficult

to understand. Much the same attitude on safety could affect the introduction of seal oil into medical research and the burgeoning natural food for nutritional supplement markets.

The safety of seal oils was actually established thousands of years ago when seal fats became a staple of the diet of many aboriginal populations in several parts of the world, including the people today called the Inuit. Many ate the seal fat raw, others after rendering it to oil by some simple heat process. Some of these procedures are described in a book called *Kabloona* (De Poncins, 1941) by a writer who spent considerable time with the Inuit in Northern Canada.

At a biochemistry level of health interest Catherine Wo obtained her doctorate with a dissertation "The Nutritional Status of Alaskan Eskimos with Respect to Fatty Acids, Vitamin A and Vitamin E (Wo, 1973). An original communication from this work appeared in *Am. J. Clin. Nutr.* (Wo and Draper, 1975). Serum cholesterol ranged upwards from 200 mg/100 ml but only a few subjects exceeded 300 mg/100 ml. Vitamin E levels were perfectly adequate despite the highly unsaturated fatty acids of the diet. This work may not have been exciting to other researchers because the health of the Eskimos on a diet high in marine mammal fats was not abnormal and consequently it has attracted little attention.

Alaskan Eskimo plasma was recently investigated for n-3 polyunsaturated fatty acids (Parkinson et al., 1994). Fish and seal fat/meat were important in the diet and platelet functions and a few rare increases in bleeding times were considered as possibly due to a low regional intake of linoleic acid rather than to a high intake of seal fat or fish oil. Adipose tissue was not examined although potentially it "warrants consideration for use in clinical studies requiring precise documentation of long-term fatty acid consumption" (Leaf et al., 1995), subject to some caution (Connor et al., 1996).

A lower prevalence of impaired glucose tolerance was also examined in Alaskan peoples (Adler et al., 1994). The report was: "Consumption of seal oil at least five times per week was required to reduce risk", an important observation. Strangely, in this connection two 1996 papers on diabetes (Rivellese et al., 1996; Rossing et al., 1996) failed to mention the long-term effects observed with native populations and focused on either short term or long term studies with humans given fish oils (both with DHA>EPA). In well-controlled studies no benefit or deleterious effect was reported for blood glucose control in the fish oil groups. A multicenter study in Italy reviewed several other recent studies on diabetics and omega-3 fatty acids and decided that the "lack of effect of omega-3 fatty acids administration on glucose metabolism in patients with impaired glycaemia control is noteworthy. It eliminates concern about prescribing these products to diabetics" (Sirtori, 1996). The above emphasis on diabetes is solely because it is now an important pathological condition in some northern populations of Canada.

Seal Oil Production and Properties

The almost pure fat of seal blubber is easily rendered by mincing and steam cooking. Unlike fish oils made from whole fish or fish waste there is very little contamination by muscle phospholipid and protein, haem pigment, or other non-fat materials. Much of the information required for a full understanding of the physical properties has been recently summarized by Shahidi et al. (1996).

In Canada, in the past, the annual seal oil production was favoured by part of the margarine industry as a marine oil alternative to avoid putting the word "fish" on the label. After standard industrial refining (Conacher et al., 1972) it hydrogenated readily.

Raw seal oil was examined for Se, As, I and Br by cyclic instrumental neutron activation analysis (Elson et al., 1983). In µg/g the results were respectively 0.033 ± 0.002, 0.73 ± 0.01, 1.82 ± 0.06 and 2.01 ± 0.28. Sulfur was 12.4 ± 0.2 mg/kg by another technique (Wijesundera et al., 1988). Tocopherols are rather low for a marine oil, about 65 µg/g in 1996 production, and in these samples PCBs are in the range 0.8 - 1.0 ppm. The latter can however be reduced by half or more along with "fishy" aldehyde oxidation products, by a simple treatment with high vacuum (deodorization). This needs to be conducted below 185°C to preserve the *cis* configuration of ethylenic bonds. At more elevated temperatures that step can alter some bonds in the EPA and DHA to *trans* (Wijesundera et al., 1989). Since this effect is commonly observed in the linoleic and alpha-linolenic acids of refined vegetable oil, especially in the alpha-linolenic acid content (Chardigny et al., 1996), it should not lead to any greater risk than Canadians derive from their regular diets. Extension of alpha-linolenic acid *trans* isomers to C_{20} pentaenoic acids is possible (O'Keefe et al., 1990), but this has no known consequences in man.

Standard refining conditions for seal oil have been described (Conacher et al., 1972) and can be contrasted with active clay, bleaching, and H_3PO_4 only (Mag, 1973). The combination of active clay, filter aid, and phosphoric acid was applied successfully to seal oil, but deodorization was omitted, presumably until after hydrogenation in this case, but the hydrogenated seal oil product seemed to have desirable flavour and stability attributes when compared to the fish oils then in use.

The fatty acids of harp seal oil are easily concentrated to give 25.5% EPA, 25.3% DHA, 9.5% DPA, 4.1% stearidonic acid (18:4n-3) for a total of 64.4% omega-3 fatty acids in free fatty acid or ethyl ester form (Ratnayake et al., 1988). The oil itself can be enriched by simple crystallization at low temperature (Shahidi et al. 1996).

Seal Oil Compared to Fish oils

The digestibility of seal oil and fish oil is effectively the same, about 95%. M.S. Christensen has examined the details of the digestive process in a series of papers (Christensen et al., 1994; 1995a; 1995b; Christensen and Høy, 1996) with experiments on Wistar rats. In the opinion of a disinterested observer, J. Dyerberg, who experimented with humans on this topic, "the isometry of the n-3 FA in the glyceride molecule does not influence the assimilation of EPA plus DHA in man" (Dyerberg et al., 1995).

Another human study with a marine mammal oil fed to humans was conducted in 1988 and lasted 10 days, with finwhale oil and a herring oil control (Weaver et al., 1989). Serum and platelet phospholipids altered their fatty acid composition in parallel for the two oils. The authors noted an increase in n-3 docosapentaenoic (n-3 DPA, 22:5n-3) acid in the phospholipids during the ingestion of the whale oil, as this fatty acid was three times as important in that oil as in the herring oil. Otherwise they found no important differences. As will be discussed below, DPA is potentially a very beneficial n-3 fatty acid and is much more obvious in seal oils than in fish oils.

An extensive study comparing seal oil, whale oil, and cod liver oil administered to humans has recently been published (Østerud et al., 1995). A daily intake of 15 mL/day was provided as a supplement to the usual diet of healthy adult Norwegians. The study focused on blood properties and seems to show beneficial effects on several blood components thought to be associated with cardiovascular and thrombotic diseases. Unexpectedly, there were inexplicable and interesting differences among the effects of the three oils that were harmless but suggest that there should be further

study. A potential problem not often encountered in this type of research with humans is the already high intake of omega-3 fatty acids from food fish or cod liver oil in Norway. From this point of view the safety of additional supplements of omega-3 fatty acids in a ten-week trial suggests that there is no problem with an intake in excess of 300 mg/day (see below).

n-3 Docosapentaenoic Acid (DPA)

This fatty acid (22:5n-3) was not considered as important as EPA (20:5n-3) in the early 1980 period because a UK research company had already discovered that EPA led to the PGI_3 prostaglandin beneficial in man. DPA was also a minor component in the MaxEPA™ type fish oils (EPA>DHA) mainly employed for research on long-chain omega-3 fatty acids. Typical fish oil levels of DPA were ≤ 1%.

Two very recent studies have amplified our knowledge of the role of DPA in mammals. Amazingly, DPA was up to 10 times as effective as EPA in stimulating the migration of endothelial cells (Kanayasu-Toyoda et al., 1996). This suggests that it is a powerful anti-atherogenic factor. In another study (Bénistant et al., 1996) DPA was found to reduce prostacyclin production in endothelial cells. Even if acting only as an instant source of EPA inside the cells, this result should encourage further interest into the biochemistry of DPA. There is no reason to consider the DPA of seal oil as a problem. It is always present in fish lipids and fish oils, usually at 10% of DHA and if present in all human milk and thus transferred to human infants by nursing mothers (see below) it can hardly be harmful.

Although several studies with humans have examined the exchange among these three fatty acids it is sufficient to note that most were based on administering purified EPA or DHA. Remarkably, the DPA has been largely ignored although it is a quarter to a third of the DHA circulating in the plasma lipid subfractions of normals. This is shown for human controls in a study of the effects of fish oil (Leaf et al., 1995). It is also an important fatty acid among the omega-3 fatty acids of human milk, for example in Australia (Makrides et al., 1995) Table 2.

Table II Fatty acids (w/w%) of breast milk supplied by mothers of fully breast-fed infants

Fatty acid	Week 6	Week 16	Week 30
18:2n-6	13.56	13.92	13.56
20:4n-6	0.45	0.40	0.39
18:3n-3	0.89	0.94	0.85
20:5n-3	0.07	0.07	0.06
22:5n-3	0.16	0.16	0.16
22:6n-3	0.26	0.21	0.19

Adapted from Makrides et al., 1995

As early as 1987 Innis and Kuhnlein (1987) reported from Canadian surveys that n-3 DPA was higher in the foods based on marine mammals available on Baffin Island than would be indicated from fish analyses. They cited similar observations in the food of Greenland Eskimos (4.6% 20:5n-3, 2.6% 22:5n-3, 5.9% 22:6n-3). They concluded "Our analyses of marine mammals and polar bear...draw attention to the complete pattern of ω-3 fatty acids in the Eskimo diet ... and the possibility of more complex interactions among the ω-3 fatty acids in influencing metabolism". In 1988 they reported on the breast milk of Inuit women consuming traditional foods (Innis and Kuhnlein, 1988). Compared to Vancouver women their n-3 fatty acids were as shown in Table 3. The two compositions obviously reflect diets but qualitatively are not very

different.

Table III Comparison of omega-3 fatty acids (w/w%) in human milks from the Canadian north and a typical urban population.

	Inuit	Vancouver
20:5	1.1	0.2
22:5	0.8	0.4
22:6	1.4	0.4

Adapted from Innis and Kuhnlein (1987)

For infants DPA is clearly provided in Canadian maternal breast milk and so can be assumed to be perfectly safe. In fact all three omega-3 long-chain fatty acids shown are normally present in human milk, a material highly recommended for infants all over the world. This is further evidence that seal oil should be harmless in man despite the presence in the fatty acids of a modest percentage, usually 2-4%, of DPA (Ackman and Ratnayake, 1989). In fact research into the effect on adults of this fatty acid uniquely available to Canadians has started (Murphy et al., in press; Holub et al., unpublished results), and needs to be extended.

Long-Chain Omega-3 Intake

A large international company, Hoffman-LaRoche, have a self-affirmed GRAS status in the USA for their ROPUFA™ food additive fish oil. Their promotional material suggests that there is a "gap" in the current food intake of western civilization of 1 g per day of these long-chain omega-3 PUFA. Many authors have tried to define the needs of EPA and/or DHA in normals for a "preventive" role in maintaining cardiovascular health, as distinct from treating hypertriglyceridemia, for which MaxEPA fish oil is licensed by the National Health Service in the UK at a dose of several grams per day.

Most medical researchers have simply ignored DPA, assuming that it was merely an intermediate between EPA and DHA. The beneficial role of EPA in the wall of the vascular system has long been accepted (Lands, 1986). The role of DHA was more obscure until quite recently when it became apparent that it could be instrumental in suppressing "fibrillation" of the heart muscle (Weylandt et al., 1996). An elegant review of this new hypothesis has just been published (Nair et al., 1997). Although DHA is thought to be the main factor (Kang and Leaf, 1996) the precursor alpha-linolenic acid can also be influential in this respect (de Lorgeril et al., 1994; Renaud, 1996)

A recent study in humans (Conquer and Holub, 1997) confirms that in both omnivores and vegetarians the retroconversion of DHA to EPA over six weeks is limited to about 10% of the dietary intake of DHA in the longer term. A surprising feature of the fatty acid analyses of both serum and platelet total phospholipids was a modest reduction in the level of **both** 22:5n-6 (DPAn-6) and 22:5n-3 (DPAn-3) as DHA increased. The EPA increased slightly as a result of the retroconversion from DHA. Whether the observation on the two 22:5 fatty acids merely reflects their physical displacement by DHA or EPA in the phospholipids, or has metabolic consequences is not known. The observation that the DPA (n-3) exceeded DHA in the total phospholipids of human platelets in both omnivores and vegetarians on their regular diets is perhaps new evidence indicative of another role for this fatty acid in addition to that already proposed. The intake of 1.62 g/day of DHA, without any EPA, over six weeks is a novel

treatment compared to both the long history of fish oil experimentation with oils or concentrates with EPA>DHA, and the historical consumption of seal fats among Arctic populations. North Atlantic seal oil is well balanced as a source of both DHA and EPA in approximately equal proportions and provides much more DPA than fish oils. As is common in these circumstances, overloading a naturally balanced system in the body with one fatty acid at the expense of others may not be appropriate for good health if a more balanced proportion is historically proven safe. Overall this work provides further confirmation of the safety of longer-chain omega-3 fatty acid intakes.

One of the best assessments of this problem of intake of n-3 fatty acids is that of Simopoulos (1989). She reports 300-400 mg per day as a desirable intake. As the conclusion from a NATO Advanced Workshop on Dietary ω3 and ω6 Fatty Acids these numbers appear to be the current acceptable figures. No doubt they were calculated solely on the basis of EPA and DHA, and inclusion of the DPA of seal oil in the total does not affect the conclusion that up to 2 g per day of seal oil with 200 mg/g of omega-3 fatty acids is in fact a daily intake of omega-3 long-chain fatty acids comparable to a capsule (1 g) of the popular MaxEPA™ products (nominally 300 mg of EPA + DHA per 1 g capsule). The seal oil provides DPA and DHA ≥ EPA, possibly an important difference from many commercial fish oils.

Conclusions

A variety of records, some going back thousands of years and some as recent as 1996, point to seal oil as perfectly safe for a role as a nutritional enhancer in our western society. The pioneering work of Dr. C.M. Harlow in this regard has been largely overlooked. There is no other practical source for the n-3 docosapentaenoic acid component, recently shown to be functionally beneficial in the endothelium of the circulatory system. It may be a part of the reasons for the extraordinary health benefits among Greenland Eskimos consuming high levels of seal oil.

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SCIENCE EDUCATION: ATTITUDE DEVELOPMENT IN SCIENCE MUSEUMS/CENTRES

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The generation of positive attitudes toward science among school students is crucial, since without it all other aspects of achievements are likely to be limited. The present study argues that science museums/centres have far-reaching potential in this regard, but the researches carried out thus far have failed to produce consistent and convincing results. This paper discusses the factors that might be responsible for this situation, and makes a number of recommendations that can be attempted in the future studies.

Introduction

Science and technology permeate society. The swift changes science and technology bring to society result in rapid changes in society itself. In the future, our dependence on science and technology can only increase as the progress continues and many areas of science and technology are at a more exciting and productive stage than ever before. The influences of science and technology in our everyday activities are increasing astonishingly, yet the gap between science and the public is widening. Universally, the avoidance of science and technology is becoming something like an obsession among school students. In majority of the classrooms, science teaching is too abstract and dogmatic - that is, astronomy without stars; botany without flowers; geology without landscapes; and optics without lenses and prisms - to make students understand science and have an inclination towards it. In the present, there can be seen a widespread concern among educators and governmental leaders for the erosion of science education in schools.

As a remedial strategy, a growing body of research emphasises the need of nurturing positive attitudes to science among students during the early school education. Koballa and Crawley (1985) suggest that students' acquisition of positive attitudes cannot be assumed to result from simply learning facts. In his Factors Affecting Schools' Success in Producing Engineers and Scientists (FASSPES) project, Woolnough (1994: 29) finds that the extra-curricular schools - those schools which encourage extra-curricular and stimulating activities (guest lectures, science club, science competition, visits, work experience in science-based industry and home experiments) - send a large proportion of their students onto higher education to continue their science and engineering. Woolnough's finding is based on the data collected (through questionnaires) from 132 heads of science and 1021 sixth formers. He also substantiates his finding from the data gathered from interviews of 87 students. Such studies suggest that some under achieving students may really get on with science very well if they were given personal satisfaction in it through the injection of 'a little extra bit' over and above syllabus.

Among teachers and students, field trips are gaining incredible popularity. The importance and educational potential of science museums, particularly of hands-on settings, known as 'science centres', has been and is being increasingly recognised worldwide. Over the years, hands-on science museums are being established at an impressive rate all over the world, including developing countries. For example, while

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there was none in the United Kingdom till the mid 1980s, today there are more than twenty science and technology centres. Similarly, in the 1980s, on average one science centre per year was developed in India.

As can be seen from the statement of mission of individual institutions[1], one of the primary objectives of science museums/centres the world over is to develop positive attitudes toward science, with special mention of youngsters. In this paper, I aim to analyze the role of science centres in attitude development. I shall first examine whether, in theory, science centres have the potential of building positive attitudes toward science or not. In the second part, I shall review the studies conducted in science museums and centres on this subject.

In the following discussion, I shall mainly focus on hands-on and interactive settings but will often consciously use the word 'museum' (with a view to discuss the findings in the broader framework) in place of 'science centre'.

Attitude Development in Science Museums

At the outset, it appears essential to think about what constitutes a museum - a curator, an architect, a building or a few objects? If we pose a simple question to ourselves - can a museum run without a curator? The right answer would be, probably yes and sometime even runs better. For example, the science museum of Thessaloniki, Greece, has been organised and successfully operated not by curators, but by visitors and fans (Iatridis, 1995). Again, if we pose another question - can a museum run without visitors? Perhaps, the answer would be - no, never or who says? This question-answer session leads us to three essential building blocks of a museum, that is the museum (container), exhibits (content) and visitors (user).

In this paper, I shall take 'essential building block triangle' as a criterion in order to elaborate the impact of a museum visit on attitude development toward science (Figure 1). In other words, I shall discuss prominent features of museums, exhibits and visitors which may successfully nurture interest in the presented subject matter, and eventually build positive attitudes among visitors toward science museums.

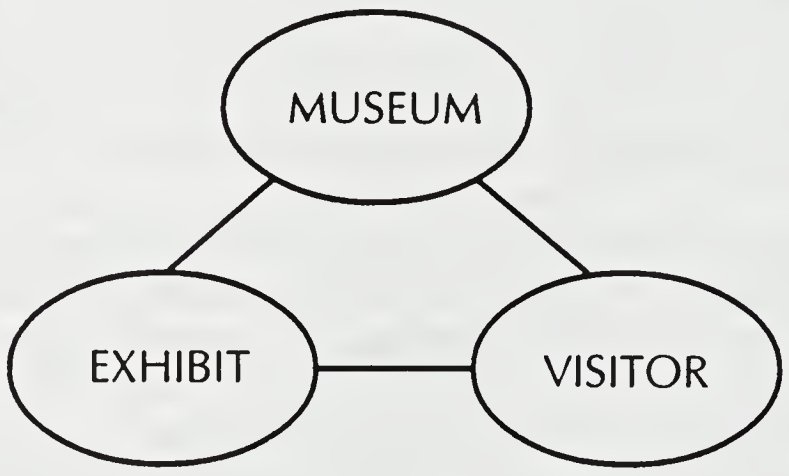

Fig 1. Essential Building blocks of a museum system

[1] The mission statement of Discovery Centre, Halifax, is: TO STIMULATE INTEREST, ENJOYMENT, AND UNDERSTANDING OF SCIENCE AND TECHNOLOGY THROUGH INNOVATIVE, EXCITING, HANDS-ON EXPERIENCES FOR ALL NOVA SCOTIANS.

Institutional Perspective

> We assembled on the spot, about ten in number, all strangers to me, perhaps to each other. We began to move pretty fast, when I asked with some surprise, whether there were none to inform us what the curiosities were as we went on? A tall genteel young man, *in person*, who seemed to be our conductor, replied with some warmth, 'What! would you have me tell you everything in the Museum? How is it possible? Besides, are not the names written upon many of them?' I was much too humbled by this reply to utter another word. The company seemed influenced; they made haste, and were silent (quoted in Hudson, 1975: 8).

The above is the museum experience of William Hutton, a bookseller from Birmingham, who visited the British Museum in 1784. Once upon a time, museums were indeed depressing, and sometimes even excruciatingly boring, environments. But since then, much has been changed. The present is an era of revival for museums as their aims and basic functions have either been changed or are in a transitional phase. For example, stress has now shifted from 'collection' to 'interpretation' and 'learning' or, in other words, from 'collection as a great achievement' to 'collection for a great achievement'.

Recognizing that most visitors do not come to museums to acquire specific knowledge, it has been, and is increasingly being, realised that learning is an informal, spontaneous and individual process in which experience itself is much more important for any significant learning to occur. Like previous times, visitors are no more 'unwanted intruders' in museums but they are 'guests' (in Experimentarium! the Danish Science Centre, Copenhagen, visitors are called 'guests'). Most of the museums have either created a visitor services or similar department or are thinking seriously in this direction. In the recent past, the majority of museum professionals have emphasised the importance of the museum as a whole in creating an environment that encourages active participation in a thoughtful and meaningful way. Ever increasingly thought is being given to each item on the learning environment inventory (Table 1).

Table 1. Details of Learning Environment Inventory (LEI) in a science centre.

Item	Description
Accessibility	Location (City Centre - high rating), transportation facility, parking and similar facilities, provisions of equal opportunities for special needs publics
Transitional Areas	Information desk, cloak room, baby changing facility, toilets, drinking water, cafe, museum shop, relaxing area, public telephone booth, children play area and first aid facility
Orientation	In person briefing of facilities, slide shows, introduction panels, museum guide book, pamphlets, sign boards, touch screens and audio guides
Circulation Choices	The provision of multi-entry and exit points, free standing exhibit units in the hall, provision of demonstration islands, small theatres, cave and dome inside the hall
Total Stimulus Control	General lighting, interior plants, thermal control, humidity control and odour control
Exhibit Editing	Colour scheme, exhibit lighting, human factors, labels (type-size, length, contrast and style, and content)

Exhibit Stimulus Rating	Cleanliness, protection, maintenance, replacement of consumable items and lost components, front staff and their professionalism
Total Integration	Indelible museum experience - no physical or psychological problem; exhibit - convey the feeling and knowledge that it is worth exploring; over-all time needed - manageable; space and time - enjoyable

To some extent, powerful drives, such as the need for personal affiliation, can mitigate many of the physical barriers. However, where the desire to learn is a less than powerful drive (an all-too-common-situation), a little inconvenience may have a marked effect. This 'long overlooked or ignored' factor has now been, or is increasingly being, identified by museum professionals as an important one:

> We believe we should be delivering quality to them (visitors), not just in terms of the content of our public galleries but also in the way in which the place is run, its cleanliness, the public facilities for it, and so on. So, we have refashioned the museum over the last three years to include high quality retailing (Neil Cossons in a interview with Januarius, 1990).

The desire to make visitors feel psychologically and physically at ease and to make the museum more attractive, both inside and out, forms undoubtedly the underlying purpose of this revival and it has largely been possible through the co-operation between museum professionals, architects, political leaders, industrial houses, and local communities. As a result today, most museums follow an holistic approach. They want the building to also convey the message in conformance with exhibits. For example, the Centre for Understanding the Environment, Horniman Museum, London, has desired that the building's design itself should speak out about environmental matters:

> It will be built from sustainable timber, insulated with recycled newspaper, finished with non-organic toxic paint, and topped with a living grass and wild-flower roof. Hollow timber beams and columns will create a natural passive ventilation system, reed beds will recycle waste water and solar panels will generate electricity (*Museums Journal*, November 1994: 8).

There is evidence that many non-users, including those who had formed their negative image about museums long ago, perhaps in their childhood, and have not attended museums since then, still hold the conventional image - museums as glorious depository of a nation's heritage (Prince and Schadla-Hall, 1985; *Museum Development*, March 1991: 25). But, the scenario is gradually emerging as a promising one. Dr Michael Gore, who visited the Exploratorium in 1975 with his family, and on his return developed his own science centre called *Questacon* in Australia, gave a very interesting account to this effect. He revealed that:

> He had to drag his family in and then, three hours later, drag them out (Duensing, 1987).

There can be seen an unprecedented increase in attendance and change in visitors' behaviour after opening up a gallery based on the science centre approach in an old museum accused of inertia by the general public. For example, following the opening

of its prestigious art and (Earth) science extension in October 1993, the National Museum of Wales, Cardiff, witnessed a leap of 36 per cent in visitor numbers (*Museums Journal*, May 1994: 25).

A further example to this effect is an ambitious exhibit, entitled *Caltex Volcanoes and Giants*, at Auckland Museum, New Zealand. In order to achieve its goals of attracting a large audience and of generating a significant exhibition income, the exhibit makes an exemplary and realistic use of display techniques and resources such as constructed environments, sound, life-size animal re-constructions and animations, interactive computers, video clips and big-screen video projectors. Following the opening of the exhibit on 6 May 1994, the museum attracted 153,000 people in the subsequent three weeks; visitation was up 100,000 on the 1993 figure for the corresponding period (Prickett, 1994).

As a result of revival, visitors can be observed now exploring things enthusiastically in new museums. They easily become absorbed in the environment. A large proportion of visitors leave the museum with a commitment to return in the near future. At the same time, a considerably large account of return visits paid to these museums confirms that visitors, in general, find the course of their visits meaningful and satisfying.

The overall perception of a visit is an extremely important factor in attitude development. Robert M. Hazen, a research scientist at the Carnegie Institution of Washington's Geophysical Laboratory, observes that 'museums can have tremendous influence. We have an opportunity here to change our national attitudes toward science' (Lantos, 1994).

Objectives of Exhibits

The exhibit is the heart of the museum, and learning from exhibits is known to be one of the prominent motivations for a visit to museums. The exhibits here are usually built upon certain objectives. According to Shettel (1968), the underlying purpose of scientific and technical exhibits is generally the same - to impart knowledge about various technical subjects, and/or to change the attitude of the viewer in a favourable direction toward science, its practitioners, and its institutions. The objectives of scientific and technical exhibits are mostly found to be educational, lately much to do with the public understanding of science and its processes. In general, these educational objectives can be crudely conceived in terms of cognitive, affective and psychomotor areas. By means of exhibits, science centres first aim to kindle in visitors' heart the wonder and loving sympathy for their content and ultimately for science, and thereafter they hope for facts to multiply in the memories of visitors:

> They expect most visitors to browse, directing their attention where they will. Through such episodic encounters with engaging material, science centres *hope to lure, stimulate, and invite* visitors to discover something new - just one thing - about the structure of the physical world' (my italics) (Grinell,1992: 13).

In exhibition halls, hands-on exhibits are changing in quality (from push button type to ones rich in varied psychomotor skills) as well as in quantity. Contemporary learning and teaching theories are increasingly being integrated with the process of exhibit development. New technologies are being employed in the exhibits to provide visitors links that would presumably facilitate learning. The interactive exhibits have been found to be the most popular ones among visitors (Thier and Linn, 1976; Alt 1983). Though interactive exhibits have been discovered to be successful in conveying

information effectively (Zelig and Pfirman, 1993), most researchers believe that individual, or a group of, exhibits may not contribute immediately and directly to the deeper understanding but their indirect effect in affective domain must not be underestimated (Wellington, 1989).

Learning theorists have long championed the idea that situational stimuli - events in the environment - directly influence our attitudes and behaviour. Roberts (1990) asserts that the nature of exhibits- multi-sensory, three dimensional, and interactive - should appeal strongly to the part of the brain that concerns with space, image and affect. True, visitors may in due course forget the detail of what exactly was displayed and encountered with, but they are unlikely to forget the enthusiasm such exhibits can generate.

Reids goes further in suggesting in his Ph.D. thesis that it is the achievement of interactivity, rather than the exact format, whether it be simulation, group discussion, or role playing, which is central to attitude development (quoted in Byrne and Johnstone, 1988). In a very extensive review of the literature, Bredmemeier and Greenblatt (1981) conclude that under certain circumstances and for some students simulation-gaming can be more effective than traditional methods of instruction in facilitating positive attitude changes.

In conclusion, all the above arguments and evidence suggest that the hands-on approach to exhibits provides a nutritious substance for attitude development toward science.

Visitors' Perspective

Learning is strongly influenced by personal world views, knowledge, attitudes and aspirations, and social interactions. Active involvement of students rests at the heart of effective science learning. Recent research points to the dominance of information processing actions in the museum environment. In a large metropolitan museum of natural history that provides ready access to novel information through its traditional displays and interactive exhibits, Hike (1989) reveals that 86 per cent of all events undertaken by visitors concern the exhibits themselves. McManus (1989), in her study of detailed discourse analysis of the recorded conversations of visitors, finds how close and personal visitors' talk is, but at the same time mediated by the labels on exhibits. Several other studies made on young visitors (Gottfried, 1980; Herbert, 1981; Alt, 1983, Carlisle, 1985; Tuckey, 1992) also reach the conclusion that children on a field trip to a science centre, at first, exhibit diverse exploratory behaviour and gradually become orderly, attentive and interested in exhibits. On the basis of these many studies, it appears reasonable to conclude that visitors through their active involvement fulfil a necessary, though it alone may not be a sufficient, condition of learning.

During the visit, visitors see a number of miscellaneous, unique and splendid things, and participate in a number of activities in a short span of time. They often see or do something which rubs-off and sticks and 'sparks-off' something in their mind which may resurface later (Wellington, 1989). Indeed, there are many, varied and scattered views about what actually visitors take away with them. Stevenson (1991) collected diversely scattered 'professional views' about visitors' assets and summarised them in six categories:

1. a set of experiences (or memories).
2. a set of effects.
3. a set of explanations.

4. a set of applications.
5. more understanding in a general sense.
6. a change in attitudes.

To make Stevenson's list further useful, on the basis of my behavioural studies (Kaushik, 1996) I suggest to include two more categories:

7. a set of brain-storming questions (or mysteries).
8. a set of misconceptions.

For category 6, Stevenson says that it is generally hoped that a visitor may feel positively disposed after a visit to a science centre. In their independent studies, both, Stronck and Birney, conclude that highly structured organised school visits appear to result in greater cognitive learning and less structured visits result in producing more positive attitude (Stronck, 1983; Birney quoted in Falk and Dierking, 1992: 50).

Attitude Change: Theory and Practice

From the above discussion, it is clear that all the three essential and mutually enlightening building blocks of a museum system, that is the museum (container), exhibits (content) and visitors, strive for the same goal - development of new attitudes and consolidation of the existing attitudes. Hence, theoretically, it can now be assumed that science museums have great potential for attitude development.

To answer the question whether science centres have been, and are, successful in the process of attitude development toward science, we have largely some anecdotal evidence. In general, exceptional and illuminating experiences act as a catalyst in the process of human development. For example, the sight of a huge electric arc as a child determined Sir Bernard Lovell's career as a scientist (described in his book *Astronomer by Chance*). Those scientists who had some contact with science museums as children usually maintain that the museums played a vital role in developing their interest in the pursuit of science (Oppenheimer, 1968; Tressel, 1992). Besides, we have also got some evidence from the general population. For example, Frank Oppenheimer talks about a woman who reported that visiting Exploratorium gave her confidence she needed to rewire a lamp. Similarly, a woman rectified a lock in her sister's house a week after visiting Launch Pad (Tulley and Lucas, 1991). Anecdotal evidence is important for the individual concerned, but as individual statements they have limited applications. It is, therefore, always desirable to establish some generalised results.

A number of quantitative research studies have already been undertaken on the aspect of attitude change as a result of exposure in museum settings. "Do attitudes change after exposure to the U.S. Science Pavilion?" was one of the main queries of the study conducted in the US Science Pavilion at the Seattle World's Fair, 1962 (Taylor, *et al.*, 1963). During their literature survey, the authors went through several constructed scales but noted that they were exploring no more than the strength of pro-or-con feelings about science (Taylor, *et al.*, 1963: 19). On the basis of literature survey and free-response interviewing, Taylor and his colleagues selected four main attitude variables: stereotypes of scientists, stereotypes of science, the meaning of scientific endeavour, and the potentials of science. They prepared an attitude questionnaire consisted of 45 items, taking 15-20 minutes to complete.

Interviews were conducted at six different locations and it was intended to find out the attitude change occurring in response to different activities or displays: that is, in

response to the *House of Science* film in Hall I, to the *Development of Science* exhibit in Hall II, to the simulated trip through space in Hall III, and so on. The majority of significant attitude changes occurred in response to the film showed in Hall I. The slight observed changes that took place after exposure to Hall II (*Development of Science*) were speculated to have occurred not as a result of the exhibits placed there but as spill overs from the changes induced by the *House of Science* film. In sum, portions of the pavilion produced changes in attitude, but the changes were of slight magnitude.

In the late 1960s, Harris Shettel evaluated an ambitious American exhibit *The Vision of Man* at the National Museum of History and Technology. The exhibit was designed to impart knowledge about the role of the federal government in science and technology and to develop a favourable attitude in young visitors toward this role. Three indices - a maximum, a minimum and a control - of effectiveness measure were established in order to determine changes occurring in three areas - knowledge, interests and attitudes. The results in the areas of interest and attitudes were found to be difficult to interpret. While the findings in interest area were found unstable, the problem with attitude data was of no difference at all. The findings here tend to show that attitudes do not seem to be influenced in response to short term exposure to an exhibit and, therefore, are found to be inconsistent with Shettel's own studies for the *Atoms in Action* exhibit (Shettel, 1973). In *Atoms in Action*, Shettel surveyed exhibit viewers and non-exhibit viewers and found that most viewers showed positive changes in attitude to the peaceful use of nuclear energy.

Borun (1977) used three sub-scales - that is, interest in science, science is good or bad and perception of impact of science - in order to measure attitudes toward science, technology and society. In her study, high pre-visit attitude became low post-visit attitude indicating that the museum experiences failed to sustain the initial level of attitude. The major weakness of this study seems to be that the author did not attempt to define her concept of attitude and its underlying structure.

In 1981, Bob Peart (1984) conducted an evaluation of exhibits (using the post-test only control group design) in the *Living Land-Living Sea* gallery of the British Columbia Provincial Museum. A questionnaire was developed to measure knowledge gain and attitude change about the seabird colonies. No significant change in attitude was found among the control and five experimental groups (1. a word exhibit, comprised of a label only, 2. a picture exhibit, also including the label, 3. an object exhibit, without the label, 4. a standard exhibit, with objects and the label, 5. a sound exhibit, with objects, the label and sound) pooled as one. Seventy-one per cent of the control group visitors were voted in favour of leaving seabird colonies undisturbed. For the experimental group, the corresponding figure was 78 per cent.

In 1984, Finson and Enochs (1987) conducted a study to determine if a visitation to the Kansas Cosmosphere and Discovery Center in Hutchinson can affect attitudes toward science-technology-society (STS). A previously developed Scientific Attitude Inventory (SAI), composed of 60 items in a statement format with a five-point Likert-type scale for responses, was employed (with slight modification) for this purpose. The items were divided into sub-scales focusing on intellectual and emotional attitudes. The authors found the building of more positive attitudes toward STS of students who visited the museum (Finson and Enochs, 1987).

In a recent survey study of teachers' reaction on the role of interactive science centres in fostering positive attitude toward science (Tuckey, 1992), respondents were asked to react to the statement, "My pupils have shown a more positive attitude towards science as a result of their visit to Satrosphere." By using this type of statement, we may perhaps not reach the right conclusion because: first, the term 'attitude' may have

different meanings to different teachers; second, teachers instead of paying critical attention to the question may respond in socially accepted terms; and third, it is an indirect study in the sense that teachers estimate the attitudes of their students and so may draw their conclusion on the basis of some bright students. The response to the above statement seems obvious (in positive terms) and so actually is the case. Sixty-eight per cent of the respondents agree strongly with the statement. In her conclusion, Tuckey (1992) also admits that changes in attitude are notoriously difficult to measure and further tries to supplement the findings by statements from children.

Discussion

All the above discussed studies seem to bring no consensus over the issue of changes in attitudes toward subject matter as a result of a science museum visitation. The researchers reported all possibilities - an increase, a decrease and no change in post-visit attitudes. In general, researchers also did not attempt to define the concept of attitude. The attitude measurement is a notoriously difficult task mainly because attitude is not a 'predefined' nor a 'stable' concept, recognised through the emergence of a shared world-view. Conceptually, attitudes are explored and defined from affective, cognitive, behavioural, biological, social and cultural perspectives. In these circumstances, in order to measure attitude changes, it becomes essential to explore and learn the way attitudes toward science are organised.

In some cases, the researchers attempted to measure attitudes by means of a single question. A single item, at its best, can tell the opinion, feeling or interest of the respondents about a particular object or event. In this context, the researchers appear to follow the assumption that opinions are verbalised expressions of attitudes. But, in real life situations, attitude matters are much more complex than these have been considered.

> ...in private, a person says all sorts of things, slurs friends, uses coarse language, acts silly, tells dirty jokes, repeats himself, makes a companion laugh by shocking him with outrageous talk, floats heretical ideas he'd never admit in public, and so forth ... that we act differently in private from the way we do in public is everyone's most conspicuous experience, it is the very ground of the life of the individual (Kundera, 1995).

This obvious fact has often been ignored by the researchers. Indeed, attitudes are nearer to pre-dispositions than opinions; they are inside and unobservable.

Some researchers also seem to assume that attitudes are organised around beliefs. Beliefs can be crudely divided into three categories: descriptive or factual (for example, science is power); inferential; and informational. In most of the cases, the researchers have employed factual statements to measure attitudes. Unfortunately, such statements have low evaluative or discriminatory power. For example, who would like to disagree with the statement that, "Science is a process of generating knowledge." Factual statements are therefore to be tested for their evaluative character before including in the final tests.

Social factor is one of the key influences which makes the problem of attitude measurement much more intricate. While responding to a question, we are generally tempted to think in socially accepted norms. Most of us would tempt to say that conservation, environment and animal rights are good and that pollution, nuclear accidents and misuse of resources are bad. These feelings are less likely to be changed

as a result of a science museum or centre visit. It is quite possible that Bob Peart (1984) did not observe any appreciable change in attitudes for this reason. To disturb seabird colonies appears to be unethical.

There is a substantial technology and associated mystique about attitude measurement. Central to this is a belief that it is not possible to evaluate something like attitude on the basis of a single statement. Through the use of a set of questions, or by getting an individual's expressed reaction to several statements, a sample of respondents' opinion should be obtained. And from this sample of opinions may be inferred or estimated people's attitudes - what they really think. Unfortunately, most of the researchers who used several items in their questionnaires appear either to have forced uni-dimensionality on the scale or to have chosen sub-scales (representing underlying attitude structure) arbitrarily or without due forethought.

In general, the researchers also did not pay due attention to the reliability and validity of their scales or questionnaires. The reliability is concerned with whether an instrument - regardless of what it truly measures - yields scores that are consistently repeatable. The question of validity refers to the issue of how we can be sure that a measure really does reflect the concept to which it is supposed to be referring. Evidently, the attitude measurement appears an useless exercise if we proceed without paying proper attention to the issues pertaining to the validity and reliability of the scale.

Conclusion

The potential of science centres in developing positive attitudes toward science seems to be far-reaching, but there appears to exist limitations or discrepancies in the research design which have so far been employed to explore the subject area. Although some correlation can be envisaged between attitudes toward science and museum visits, positive attitude changes have not been convincingly confirmed. What is needed first and foremost is the construction of the attitude concept after taking into account of its affective, cognitive, behavioural, biological, social, cultural and religious associations. Uni-dimensionality should not be unilaterally enforced on the attitude concept. In order to infer and examine the underlying structure of attitude, multi-factor analysis can also be employed.

Much additional research has yet to be done on appropriate research tools. This can be done either by refining existing attitude scales or developing new valid and trustworthy scales for measuring attitude changes in response to a science museum visit. While conceptualising questionnaires, factual and socially accepted statements should be avoided. It is, therefore, recommended that future studies include the gathering of qualitative data to define attitude concept, developing instruments that could meaningfully represent to those concepts, and convincingly confirm the relationship between attitudes toward science and science museum visitations. The task is original and challenging, yet achievable.

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ATLANTIC REGIONAL WORKSHOP ON THE COMMERCIALIZATION OF GOVERNMENT SCIENCE RESEARCH: SUMMARY

NOVA SCOTIA AGRICULTURAL COLLEGE, OCTOBER 4, 1996

On October 4, 1996 the government Task Force on Commercializing Government Science Research held an Atlantic Workshop in Truro, Nova Scotia. The workshop, attended by the Chair of the Task Force, Walt Lastewka, and Vice Chair, Dianne Brushett, solicited ideas and suggestions from a variety of stakeholders in the university and government communities. Dr. Réné Lavoie from the Science Branch of Fisheries and Oceans Canada in Halifax provided an engaging and informative luncheon address. Bob Russell from the *Strategis* Program at Industry Canada in Halifax followed the luncheon address with an excellent overview of current R&D statistics.

All of the participants provided valuable comments and insights, and wished to send the following clear message to the Government of Canada:

As a country, Canada must endorse and financially support basic science research. The federal government must provide leadership in R&D by committing adequate, stable funding for research initiatives and infrastructure, by promoting research efforts and careers, and by enhancing and enabling partnerships between universities, industry, and government that will foster the commercialization of research and technology. Currently, Canada spends less of its GDP on research and development (1.5%) than any of the other G-7 nations. R&D is a crucial part of effecting jobs and growth in the current knowledge-intensive global economy, and the government must make a definitive commitment to improve the current state of R&D funding and promotion in Canada.

Recommendations for Improvement

Each individual university had its own ideas and recommendations on how to capitalize on R&D opportunities. Among the more noticeable recommendations were the streamlining of research firms, smarter government funding, partial privatization of government research agencies, and more early business involvement with university research.

Successful partnerships and collaborations are vital to strengthening Canada's potential for commercialization and productivity in research. Linking Canadian businesses with Canadian researchers is a valuable method of keeping experts and their expertise, as well as business investments in Canada. Currently, university labs are relatively isolated from business. This, however, is changing and both universities and businesses are learning to be more cooperative and receptive to each other's needs and ideas. All of the **participants stressed the importance of human contact in the partnering process**.

Participants agreed that government funding and cooperation, and the restructuring of R&D infrastructure in Canada are crucial to commercialization success. More specifically, participants felt that the federal government must commit to secure, long-term funding, and actively work to eliminate bureaucratic red tape that is a disabling factor in the current process. Many noted that the quality of funding decisions and investments is equally as important as the quantity of funding the government invests.

Some participants argued that current funding is simply spread too thin and that a pooling of government funds into streamlined government/university research facilities would go a long way in creating a more efficient and productive system that could provide a more diverse and extensive base of expertise.

Universities and their researchers need incentives to become more entrepreneurial with their research. While teaching and research excellence are adequately rewarded, there is no mechanism in the current system to reward entrepreneurial initiative or excellence. Many agreed that greater freedom and incentive must involve the university awarding patents to individual researchers which allows them to sell their ideas to business or to develop and market them on their own. A growing number of researchers have developed "spin-off companies" which result in research being developed into a finished product. Many argued that giving researchers full ownership and enhanced freedom would do much to increase the speed with which research goes from the lab to the market.

Many participants felt that **financial incentives** are generally the most effective. Most agreed, that **an R&D tax credit is fundamental**, especially if small businesses are to get involved and stay competitive. Financial incentives could also include a better capital ventures program to help researchers with expensive equipment costs. There is an opportunity for government to establish a site on the internet, linking current research topics with current business needs and a list of possible available government programs that provide R&D and industry funding. ACOA is a good example of how a government liaison can be effective in facilitating successful partnerships and linking good ideas with funding opportunities.

Currently, a lack of receptive industries, a limited choice in Canadian companies and an absence of leadership are barriers to the improvement and success of research commercialization. Most Atlantic universities do not have an office dedicated to marketing university research and expertise to private sector industries and they consider this lack of infrastructure to be a significant barrier. Not surprisingly, questions of ownership also hinder progress. Attitudes, however, are changing, and most of those involved now agree that it is better to own 20% of something profitable than 100% of something that never gets off the shelf. Generally, participants felt that if a project is government-funded, it is public information. In the case of universities, ownership should be divided 50/50 between the university and the faculty member or graduate student. In cases where industry provides significant funding, they too are entitled to part of the ownership.

Many participants agreed that it is important to recognize that Canada cannot compete in all areas. Instead, government and universities must apply new technology to industries in each region where there is already expertise and experience. Others, however, felt that research should not be limited to regions because it thwarts international recognition and hampers Canada's ability to attract international students.

Measuring Success

Success cannot be measured by numbers alone. A lot of the research that universities perform has broader applications and benefits for society which cannot be measured in any scientific way. Accountability is a large part of measuring success. It is important that those in charge of evaluation do not try to count too many things or count them too often. Participants agreed that one of the toughest challenges they face is being able

to provide a continuum of funding for research and commercialization ideas. Without this continuum, it is impossible to measure or indeed achieve real success. Most participants agreed, that there should be a time and funding commitment of at least a decade if government and universities hope to measure improvement in a meaningful way. While long-term measures will tell the real story, short-term measures of success must also be used in order to maintain interest and awareness in progress.

It is not enough to count an increase in the number of patents, researchers, or projects. Indeed, it is more meaningful to assess whether or not a patented product will still be valuable in ten years, or to count how many strategic alliances have been formed between government, universities, and industry. Any measure of success must take into account the unemployment rate, as well as the number of jobs that have been maintained and created as a result of the new government strategy. Measuring the number of jobs that result *indirectly* from success in the high- tech sector is also an important component of this process.

Conclusion

No one expects the federal government to tackle this burden alone. Universities and industry are both willing to invest time and money in accordance with the federal government's effort to improve commercial opportunities for R&D. Canada's future competitiveness depends on its ability to adapt to a high-tech, knowledge-based economy, and the ability to get research from the laboratory to store shelves is key to achieving such an economy. Given that it boasts a skilled workforce and many excellent university and research facilities, participants at the workshop agreed that Canada should be able to meet these new challenges head on with tremendous success.

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Volume 41, Part 3, pp. 130-133.

PRESIDENT'S REPORT
1996-1997

The Council of the Nova Scotian Institute of Science initiates the following main activities:

regular lectures;
publication of the Proceedings;
maintaining its library;
providing a collective voice for scientists in Nova Scotia;
providing services related to science to scientists and the community in general.

LECTURES

The following lectures and panel discussions were presented:

October: How we communicate by smell?
Dr. Richard Brown, Psychology Dept., Dalhousy University.

November: panel discussion: "Entrepreneurs in the University".
Dr. Abdulah K. Kirumira, President "Octopus Diagnostics Research" (medical biotechnology),
Dr. Marlon R. Lewis, President "Satlantic Inc." , Halifax
Dr. Andrew C. Peacock, "BDI: Business Development Information Inc.", Halifax
Dr. Doug Pincock, President "Applied Microelectronics Inc. (AMI)", Halifax.
Moderator: **Dr. Rollie MacInnis**, Deputy minister, Technology and Science Secretariat.

December: New dates for old things: radiation dosimetry, megafaunal extinctions, and archaeology.
Dr. Dorothy Godfrey-Smith, Earth Sciences, Dalhousie Univ.

January: panel discussion: "Aquaculture Science in Nova Scotia: are we heading in the right direction?"
Dr. John Loch - Regional Director of Science, Fisheries and Oceans Canada
Dr. Roger Foxall - Director General, Institute for Marine Biosciences, National Research Council of Canada
Dr. Roland Cusack - Veterinarian, Nova Scotia Department of Fisheries
Dr. Tom Gill - Director, Canadian Institute of Fisheries Technology, TUNS
Ms. Marli MacNeil - Executive Director, Aquaculture Association of Nova Scotia
Mr. Peter Darnell - Indian Point Mussel Farms
Mr. Louis Deveau - President, Acadian Seaplants Limited
Mr. John Batt - Research Director, Sambro Fisheries Limited
Mr. Philip Drinnan - Loch Bras d'Or Salmon Farms
Moderator: **Dr. Rene Lavoie,** Assistant Director, Science Branch, Fisheries and Oceans Canada.

February: On the road to electrical vehicles with long driving range.
Dr. Jeffrey Dahn, Physics Department, Dalhousie University.

March: New insights into Artic Ocean circulation revealed by the transport of radioactive waste.
Dr. John Smith, Marine Environmental Science Division, BIO.

April: panel discussion: "Science curriculum at the high school"
Bob Leblanc - Director English Programme Services, NS Department of Education.
Brian Cochran - Science Consultant, NS Department of Education.
John Haysom - Professor, Department of Education, Mount Saint Vincent University.
Bob Braedley - Consultant with Chignecto Regional School Board; member NSTU.
Jim Sutherland - Physics teacher Queen Elisabeth High School.
Moderator: **Dr. Lucy Kanary**, Chair of the Discovery Centre Board; Director Advanced Material Engineering Centre (AMEC)

May: Gene cloning: methodology and applications.
Dr. Jonathan Wright, Biology Department, Dalhousie University
From genes to humans: some ethical implications of cloning".
Dr. Susan Sherwin, Philosophy Department, Dalhousie University

As is apparent from the above, we introduced this year more panel discussions. They were extremely well attended, regularly exceeding the capacity of the lecture room at the NS Museum, despite the extra chairs. It is clear that there is a need within the scientific community to discuss pertinent issues. Despite the fact that organising such panels requires a large time commitment, organizing such panels on "hot topics" should remain a major responsibility of Council. I thank the different members of Council who organized or helped organize these events and the speakers for their willingness to participate.

PROCEEDINGS:

After reorganising the responsibilities for publishing the Proceedings, one issue (consisting of two parts) of the Proceedings was published and a second issue is well on its way. It is essential to us that the Proceedings are published regularly, becomes more readable to a larger audience and focuses on a broad range of issues relevant to scientists in NS. The new editor Dr. R.P. Gupta, has made major steps in this direction, and we thank him for his directness and energy with which he accepted the responsibility as editor. For the next issues he will be assisted by Dr. Stephen Payne as managing editor.

LIBRARY:

Maintaining the library is an important function of Council. This year the library was moved to another room of the DAL Killam Library. With the help of a summer student the holdings were reassessed; duplications with other regional institutions prevented. The Proceedings are sent out to our members and about 200 sister organisations across the world; in return we receive a similar amount of journals. These journals are listed on our Web page. They are catalogued and stored by our librarian Sharon Longard. We thank her sincerely for her hard work to maintain this valuable collection.

REPRESENTING SCIENTISTS.

You might remember that last years speaker at the annual meeting was Rolly MacInnes, Deputy minister of Science and Technology Secretariat. We have kept contact with him and he was the moderator on our panel of Scientists as Entrepreneurs.

Several political issues came up that required our input. We wrote letters and had discussions with MP's and MLA's to support of Science funding to this region. With elections coming up we will again draw attention to these issues as well as employment opportunities for young scientists in this region.

SERVICES TO SCIENTISTS:

We have made more extensive use of e-mail to alert members and other scientists to science activities in this area in general and that of the Institute in particular. A monthly e-mail newsletter was introduced.

The NSIS web-site now includes:

- history and activities;
- details about our meetings;
- information about the Proceedings, including its table of content;
- titles of the periodicals held by the Institute;
- directory of research facilities in this region.

We also introduced a page describing the research activity of its members. I encourage members to publicise their activity to the general public and to attract potential graduate students this way.

We thank Dr. Stan Heaps for taking charge of the Web-site and maintaining it so professionally.

SERVICE TO THE COMMUNITY:

On the initiative of R.P.Gupta we started last year a science workshop for grade 5 and 6 students. This was repeated this year. Both times the workshop was led by Surjeet Verma, now member of Council. We thank him as well as Dr. Sherry Niven, Peter Lockard and Dr. R. P. Gupta for organising this event this year. 32 students and parents were invited. It was a great and successful event.

MEMBERSHIP:

Although still sizable, an area of concern is its decline. It is not clear to many scientists why one should become a member of the NSIS. Despite this we will continue our membership drive spearheaded by our membership committee of Drs. Heaps, Niven and Loucks. Among other initiatives, they advocate more involvement of the membership in NSIS activities. It is clear that we need to be more visible and explain more clearly our role. With this in mind we have publicized our activities more widely through e-mail and fliers. This way we hope to make the community more aware of what "they get for their $15.-".

I like to take this opportunity to thank the Nova Scotia Museum for its financial contribution towards the Proceedings and for providing space and facilities for our

meetings and lectures. By doing so it demonstrates its support to the Institute which is greatly appreciated.

In conclusion, it has been an active and productive year, which would not have been possible without the hard work of all members of Council; I thank them for their commitment to the Institute.

Submitted by:

Gerhard Stroink,
May 5th, 1997.

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PROCEEDINGS

of the

Nova Scotian Institute of Science

HALIFAX, NOVA SCOTIA

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GOAT LAKE, A WARM WATER, ESTUARINE REFUGIA FOR MOLLUSCS ON THE SOUTH SHORE OF NOVA SCOTIA

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Goat Lake is a tidal, silled, 11.5 m deep lake-like estuary situated off Mahone Bay on the Atlantic coast of Nova Scotia. The lake is flushed for 2 h and 21 min during an average high tide, and requires between 8 and 32.4 days for complete exchange depending on stratification conditions. Salinity at depths below 3 m average 28 °/°°. A 0.5-1 m surface layer of brackish water in combination with the limited flushing led to periods of anoxia in water deeper than 5 m. Maximum surface temperature was 25.1°C during the summer and average summer surface temperature was 2.8°C above adjacent Mahone Bay. Goat Lake has reproducing populations of the ribbed mussel, *Geukensia demissa* and American oyster, *Crassostrea virginica* which rarely occur along the south shore of Nova Scotia. Unique marine ecosystems, such as Goat Lake, should be surveyed and some possibly placed on the list of protected, natural heritage sites in the province of Nova Scotia.

Goat Lake, situé en dehors de MaHone Bay sur la côte atlantique de la Nouvelle-Écosse, est un estuaire sujet à la mareé, profond de 11.5 m avec un seuil et avec l'apparence d'un lac. Ce lac est inondé pendant 2 h et 21 min lors d'une moyenne haute mareé, et a besoin de 8 à 32.4 jours pour un échange complet, dépendant des conditions de stratification. Au dessous de 3 m, la salinité a une moyenne valeur de 28 °/°°. Une couche superficielle d'eau saumâtre de 0.5-1 m, avec un débordement limité, a produit des périodes d'anoxie dans l'eau en dessous de 5 m. La température superficielle maximum pendant l'été était 25.1°C et la température superficielle moyenne pendant l'été était 2.8°C plus élevée que celle de la Mahone Bay avoisinante. Il y a dans Goat Lake des populations reproductrices comme la moule à côtes *Geukensia demissa* et l'huitre américain *Crassostrea virginica*, deux espèces que l'on trouve rarement sur la côte sud de la Nouvelle-Écosse. Les écosystèmes uniques, comme ceux de Goat Lake, devraient être surveillés, et, si possible, placés sur la liste des sites naturels protégés en patrimoine dans la province de la Nouvelle-Écosse.

Introduction

Goat Lake is a marine, tidally influenced, lake-like, silled estuary located in Lunenburg County, Nova Scotia (44°58'16"N, 64°21'05"W). Goat Lake appears to be a freshwater lake with a short outflow creek that runs through a salt marsh emptying into Secret Cove, Mahone Bay. However, water flow reverses to flow into the lake at high tide. The situation is similar to the Saint John River at Reversing Falls gorge where a sill restricts the inflow and outflow, causing a reduction in the tidal range of the estuary in comparison to the Bay of Fundy (Metcalfe et al., 1976).

We found populations of ribbed mussels, *Geukensia demissa* (Dillwyn, 1817) and American oysters, *Crassostrea virginica* (Gmelin, 1792) in Goat Lake. *Geukensia demissa* is a mud-dwelling mussel of salt marshes on the Atlantic coast of North America occurring from the Gulf of St. Lawrence to Florida and along the Gulf of Mexico from Florida to Yucatan (Bertness, 1980; Brousseau, 1984; Lin, 1989). It is reported to be very scarce north of northern Massachusetts (Franz, 1995) and is extremely rare in Minas Basin (Bleakney and Meyer, 1979). The American oyster has a range similar to the ribbed mussel, but is rare along the Atlantic shore of Nova Scotia.

Our study examined the hydrographic characteristics of Goat Lake including the amount of tidal flushing. Temperature, salinity, and dissolved oxygen were monitored between May and November during 1995 and 1996. The life history characteristics of the ribbed mussels in Goat Lake were studied including the annual gonadosomatic

* Author to whom correspondance should be addressed.

cycle of the adults, spat-settlement, and demographics to determine if this isolated population is self-reproducing.

Our original objective in this research was to locate suitable warm water habitat for use as a nursery for shellfish aquaculture. With the discovery of the unique shellfish species occurring in Goat Lake and its unsuitability for a nursery due to anoxic conditions, we decided to describe the lake and present it as a candidate for inclusion in Nova Scotia's protected, natural heritage areas.

Materials and Methods

Morphometry and Hydrographic Mapping

An outline of Goat Lake was obtained from a 1:4800 topography map compiled from aerial photographs taken from Hubbards to East Chester. Goat Lake was enlarged from the East River section to 1:3400 using a photocopier. Morphometrics were measured using a centimeter ruler to the nearest millimeter and converted to meters using the map scale (1 mm = 3.4 m; Fig 1). A depth contour map was compiled from depth soundings taken along a series of transects across Goat Lake. A small craft starting at one boat length from shore was run at constant speed along each transect. Soundings were taken at 15-second intervals using a Royal RF-120 depth sounder.

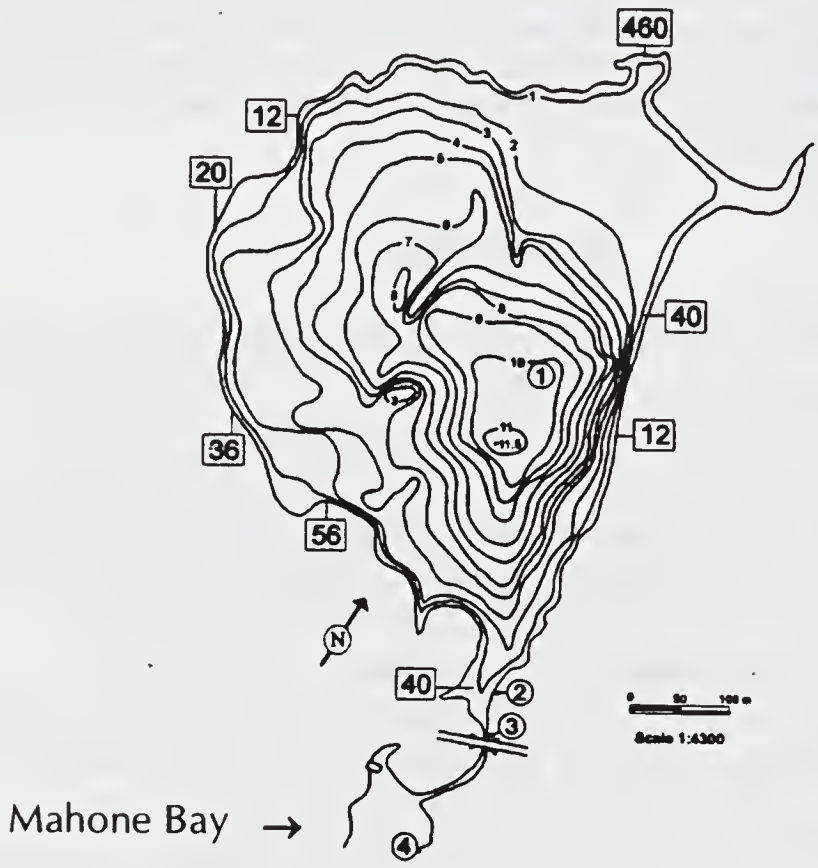

Fig 1 Bathymetric map of Goat Lake, Lunenburg County, indicating stations 1-4 and density distribution of ribbed mussels, Geukensia demissa (mussels/m^2) at representative stations (in squares). Contour intervals are 1 m.

From the bathymetric map; maximum depth (Zmax), mean depth (Z), relative depth (Zr), volume development (Z/Zmax), surface area (m^2), and volume (m^3) were determined (Cole 1994). The volume of the lake was determined by two methods, integrating a hypsographic curve and adding the volumes calculated by a geometric

formula for each depth interval. The final volume was taken as an average of the results of these two methods.

Water Levels, Tidal Flow, and Flushing Time

Water levels are expressed with reference to the minimum level in 1995 measured using a self-made tide gauge since no benchmark is easily accessible (Welch, 1948). The tide gauge consisted of a wooden stake marked off in 0.5 cm gradations. Tidal flow for a spring, neap, and two average tidal cycles were recorded at station 3 using a T.S.K. 3725 Tsurumi-Seiki Co. Ltd. Current-meter suspended in the inflow\outflow channel connecting Goat Lake to Mahone Bay. The flushing time (t) in tidal periods was determined using the "tidal prism method" outlined by Bowden (1967) such that

$$t=\frac{V+P}{P}$$

Where: V = total volume of the estuary at low water and,
P = volume of water entering during flood tide (intertidal volume).

The flushing calculations considered tidal exchange as the main mixing process and used data on the tides and physical dimensions of the lake. Freshwater inflow was ignored since the streams entering the lake were negligible in size most of the year. The "tidal prism method" assumed that all water entering during flood tide becomes completely mixed with the water in the estuary and the ebb flow consists of this mixed water (Bowden, 1967). Salinity data was used to determine whether mixing was vertically complete or not. If it was not complete, the flushing time was corrected to only include the volume of water, which was actively mixed from that vertical depth to the surface (Ketchum, 1951).

Water Analysis

Water analysis was conducted over the two-year study period with tri-weekly readings from May to November. Temperature and salinity measurements were taken for surface waters, 0.5 m, and from 1-10 m at one meter depth intervals at station 1 in Goat Lake (Fig 1). Comparative measurements were obtained in Secret Cove, Mahone Bay for surface waters, 0.5 m and from 1-3 m at one-meter depth intervals. Temperature (°C) and salinity (°/°°) readings were measured using a YSI Model 33 S-C-T meter with a probe cord graduated at 1 m intervals, after calibration using a mercury thermometer.

The number of degree days above 10°C was determined for surface waters and at a depth of 3 m at station 1 in Goat Lake to determine if there was any significant shift in the temperatures between 1995 and 1996 (Mann-Whitney, 95%). Comparative temperatures between Mahone Bay and Goat Lake were analysed using degree-days (Mann-Whitney, 95%) for the period from May 8 to November 2, 1996.

Dissolved oxygen samples were obtained using a Nissan water-sampler at station 1 in Goat Lake for surface water, a depth of 0.5 m, and 1-10 m at 1-m intervals. Water samples were also taken at station 4 in Secret Cove, Mahone Bay for surface waters and at a depth of 2 m. The Winkler method was used to determine dissolved oxygen (Welch, 1948).

Biota of Goat Lake

The fauna of Goat Lake was collected by hand, while wading or by snorkeling. Organisms were visually identified onsite or collected for later identification. Emphasis was placed on species uncommon to marine waters of the Atlantic coast of Nova Scotia

such as the ribbed mussel, *Geukensia demissa* (Bleakney and Meyer, 1979). Distribution of mussels within the lake was observed by wading along shore or by snorkeling. Mussel densities were determined at each location (indicated by numbers in squares in Fig 1) by placing a 0.25 m^2 quadrant on the bottom and counting the number of individuals inside. Demographics of the population were assessed by picking samples of ribbed mussels by hand at various locations within the lake to a maximum depth of 0.5 m. Care was taken to collect all mussels within a given area to prevent bias towards larger sized individuals. Shell length was measured and recorded to the nearest millimeter using a measuring board. Mussels were then returned to the exact locations from which they were removed. Shell length histograms were created by dividing length data into 9 size classes ranging from 0-90 mm.

Samples of 10-12 ribbed mussels were taken on a bi-weekly basis over the sampling period in order to monitor gonadosomatic development. Individual mussels were scrubbed and excess byssus was removed for measurement of total mass (g). The mussels were steamed for approximately 5 minutes at 100°C to remove the body from the shell. The shell mass (g) was measured and subtracted from the total mass (g) to determine the wet body weight. The remaining byssus was removed with dissecting scissors. The body was placed within labelled tin cups and dried for 24 hours at 150° C to find dry body weight. For each year, samples were analyzed by setting a standardized shell length (one-way ANOVA, P=0.05) to determine a size range with no statistical significant difference between mean shell lengths of collected samples. Mean dry body weight (g) and mean wet body weight (g) were determined for standardized mussel samples and statistically analyzed (one-way ANOVA, P=0.05) to determine when significant drops in body weight occurred during the year which was assumed to indicate spawning.

Results

Morphometry and Hydrographic Data

Goat Lake has a maximum length of 685 m, maximum breadth of 597 m, mean breadth of 296 m, a shoreline length of 2,370 m and an area of 20.2 ha (Table I). Goat Lake is relatively shallow. Mean depth is 4.12 m and relative depth 2.25% (Table I). The maximum depth of 11.5 m, occurs in a central basin (Fig 1). The average volume determined by integration of a hypsographic curve and by geometric formulas is 8.35 x $10^5 m^3$ (Table 1).

Table I Morphometrics, morphometry, and flushing time of Goat Lake determined from 1:3400 hydrographic map.

Maximum length (l)	685 m
Maximum breadth (b)	597 m
Mean breadth (b)	296 m
Shoreline length (L)	2.37 x 10^3 m
Area (Ao)	20.2 ha
Maximum depth (Zmax)	11.5 m
Mean depth (Z)	4.12 m
Relative depth (Zr)	2.26%
Average volume	834,692 m^3
Development of volume	0.358
Average tidal range ±max/min.	5.5 ±15.0/1.0 cm
Flushing time with incomplete vertical mixing	15.0 tidal periods
Flushing time with complete vertical mixing	60.7 tidal periods

Water Levels, Tidal Flow, and Flushing Time

The water level in Goat Lake varied with the season and also with the tide on lunar cycle rather than a semi-diurnal cycle. The tidal range measured with the tide gauge indicated an average increase in water level of 5.5 cm during flood tide when water was flowing into Goat Lake.

Flood tides lasted 2 hours and 21 minutes on average. The longest inflow durations of 3 h 9 min and 3 h 2 min occurred during spring and neap tides, respectively (Table II). During 1995, average inflow (flood) and outflow (ebb) velocities were 0.631 m/s and 0.709 m/s, respectively. Maximum velocities recorded during inflow and outflow were 1.03 m/s and 1.01 m/s, respectively. Flushing time, calculated using the "tidal prism method" (Bowden 1967), was 60.7 tidal periods during complete vertical mixing periods such as turnover (Table I). Since a semi-diurnal tidal period is 12.8 hours, the lake required 32.4 days to flush its entire volume during these periods. Incomplete vertical mixing during the summer due to stratification involving the upper mixed layer to a depth of 1 m, reduced flushing time for this layer to 15.0 tidal periods or 8.0 days (Table I).

Table II Flushing characteristics for one neap, one spring and two average tides measured at station 3 during 1996 indicating duration of inflow and intertidal volume (P).

Date	Class of Tide	Duration of inflow	Intertidal Volume(m^3)
June 18	Average	02.31	9.7×10^3
July 11	Average	01.52	4.9×10^3
July 24	Neap	03.02	14.2×10^3
August 2	Spring	03.09	27.1×10^3

Water Analysis

Weekly temperature recorded during 1995 and 1996 indicated a typical lake profile with a strong thermocline developed by late June at a depth of 3-4 m (Fig 2). The thermocline sunk to greater depth as surface waters cooled during the fall. During 1995, temperature reached 25°C in the upper 0.5 m of water in August and temperature at the bottom rose to 9°C by November. The brackish water floating on top of denser salt water lead to inverse thermal stratification intermittently in the first meter of water during summer and fall (Fig 2). The total number of degree-days above 10°C from June 14 to November 2, 1995 for surface waters was 2,704 and at a depth of 3 m, 2,390 degree-days.

During 1996, a strong thermocline developed in mid-June at a depth of 1-2 m and remained at a depth of 2.5-3.5 m until mid-August (Fig 2). Temperatures of 25°C were recorded at the surface during September and bottom temperatures rose to 8°C by October. Inverse thermal stratification in the upper meter of water was observed during mid-July and in October. The total number of degree-days above 10°C for surface waters and at a depth of 3 m between June 14 to November 2, 1996 was 2,777 and 2,221 degree-days, respectively. Statistical comparisons indicated no significant difference in degree-days between 1995 and 1996 (Mann-Whitney, P=0.05).

Water temperature monitored between May 8 and November 2, 1996 in Secret Cove, Mahone Bay (Fig 1) indicated lower temperatures occurred there than observed in Goat Lake. On May 26, surface temperature was 4.0°C in Secret Cove compared

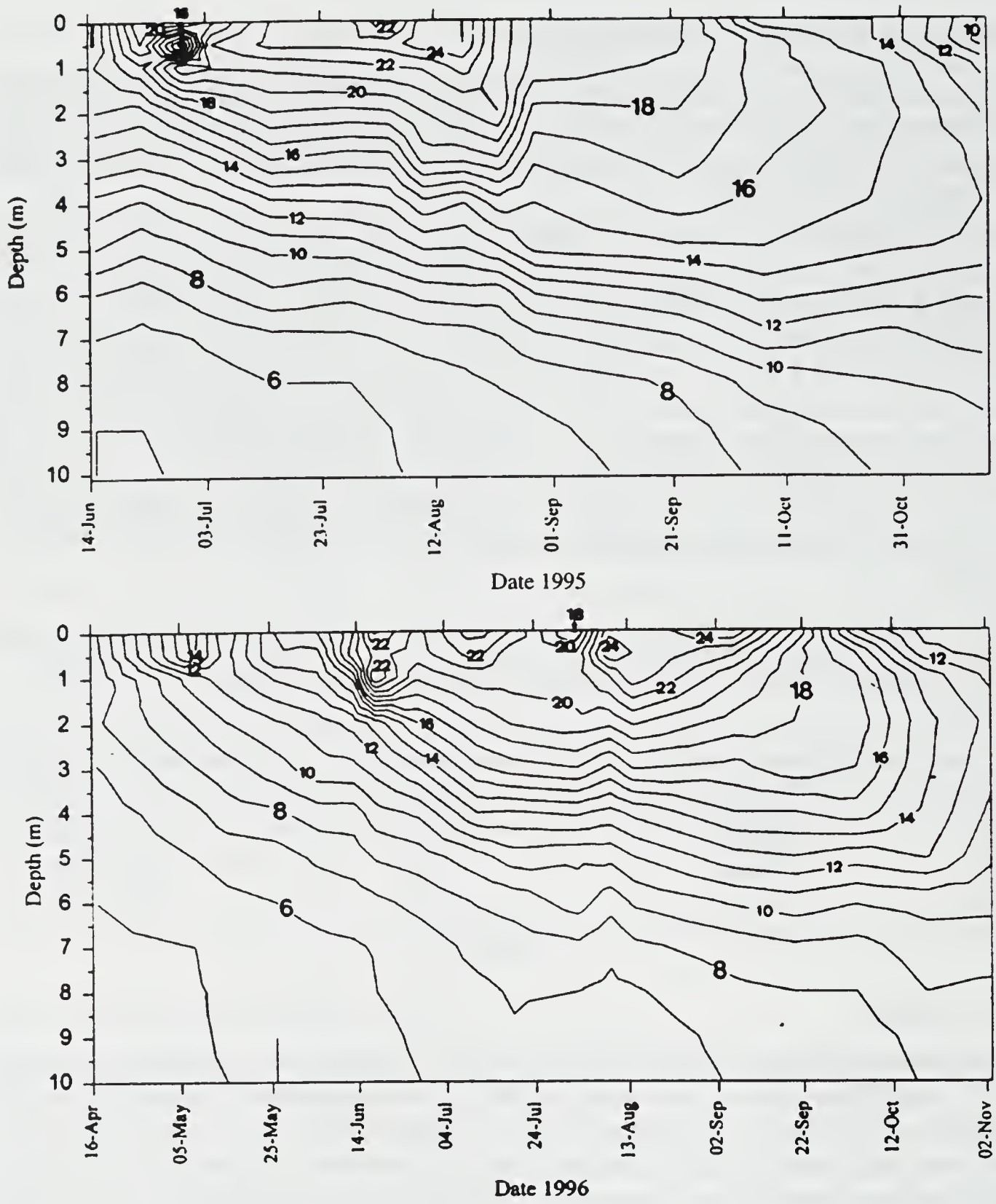

Fig 2 Temperature (°C) isopleths at station 1 in Goat Lake during 1995 and 1996.

to surface temperature of 15.0°C in Goat Lake. A maximum surface temperature of 23.5°C was observed in Secret Cove on August 9 when the comparable temperature was 23.7°C in Goat Lake. The maximum surface temperature of 25.1°C observed in Goat Lake was on September 6 when Mahone Bay was 18.0°C on the surface. On certain occasions, the ocean was warmer than Goat Lake, but on average, the surface temperature of Goat Lake was 2.8°C above adjacent Mahone Bay. The number of degree-days above 10°C in Goat Lake compared to Secret Cove were 3,301 versus 2,832 for surface waters and 2,574 versus 2,294 at a depth of 3 m. Statistical analysis indicated there was a significant difference in water temperatures at the surface and at a depth of 3 m between Goat Lake and Mahone Bay from May 8 to May 26, 1996 (Mann-Whitney, P=0.05). Goat Lake warms much faster than Mahone Bay. Goat Lake also remained warmer in early fall, but surface waters rapidly cooled with the onset of

cold weather during November. Water temperatures at the surface and a depth of 3 m at stations 1 and 4 from September 6 to November 2, 1996 showed no significant difference between Goat Lake and Mahone Bay (Mann-Whitney, P=0.05).

Salinity measurements in Goat Lake during 1995 and 1996 indicated the formation of various pycnoclines and meiohaline conditions. A maximum salinity of 30.9o/oo was recorded at a depth of 7 m on June 29, 1995 and a minimum of 0.2o/oo at the surface on July 19, 1996. A halocline occurred within the first meter throughout most of the study period where salinity ranged between 4o/oo and 24o/oo (Fig 3). Salinity deeper than 1 m remained isohaline throughout the study period at an average salinity of 28.5$^{o/oo}$.

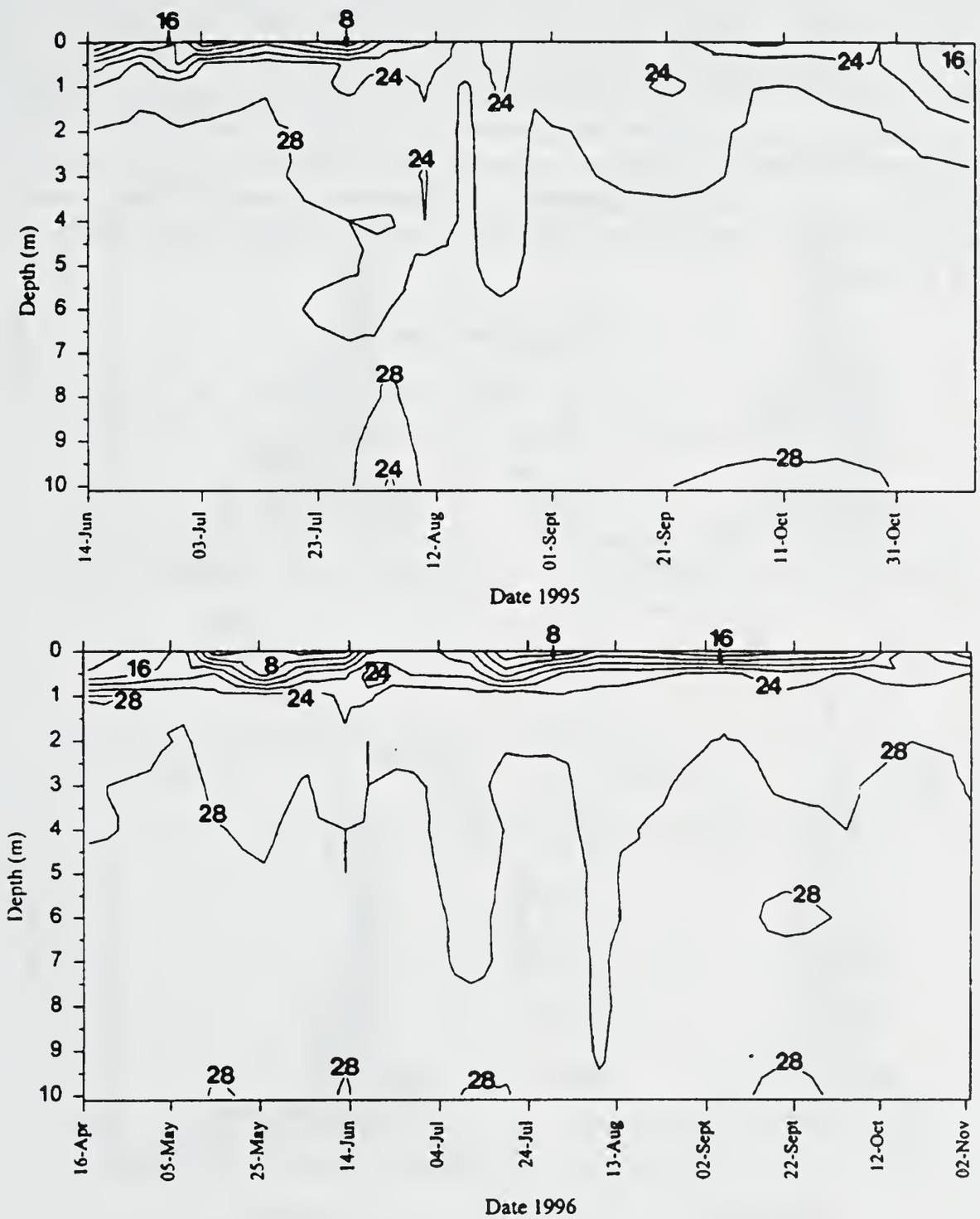

Fig 3 Salinity isopleths (o/oo) at station 1 in Goat Lake during 1995 and 1996.

Comparative salinity measurements were taken in Mahone Bay during 1996 from May 8 to November 2. A maximum salinity of 29.6 o/oo was recorded at a depth of 0.5 on May 26 and a minimum of 11.3 o/oo at the surface on June 13. During periods of brackish water within the surface meter of water, salinity ranged from less than 12 o/oo to 24 o/oo. The salinity of water below 1 m remained relatively isohaline at an average salinity of 28.2 o/oo.

Dissolved oxygen was determined during the fall of 1996 in Goat Lake and comparative data was collected in Mahone Bay. At the surface, the lowest oxygen concentration of 6.5 mg/L was related to a brackish layer of water of 20.2°C and a salinity of 7.0o/oo on September 20. Between the depths of 0.5 m and 5 m, dissolved oxygen decreased from 7.6 mg/L to 0.2 mg/L. At a depth of 6 m to the bottom at 11.5 m, there was no dissolved oxygen present. On October 4, oxygen at the surface was 9.01 mg/L in a brackish layer of 13.2°C and a salinity of 7.5 o/oo. From a depth of 0.5 m to 5 m, dissolved oxygen decreased from 9.11 mg/L to 0.1 mg/L, and anoxic conditions occurred from 6 m to the bottom (Fig 4). The presence of dissolved hydrogen sulfide, associated with the lower anoxic saline layer was first noticed on July 19, 1996 from the odor of a water sample taken at a depth of 8 m. By September 6, this odor was noticeable up to a depth of 6 m. Oxygen determinations made in Mahone Bay on September 20 and October 4 yielded an average oxygen concentration of 8.0 mg/L at all depths.

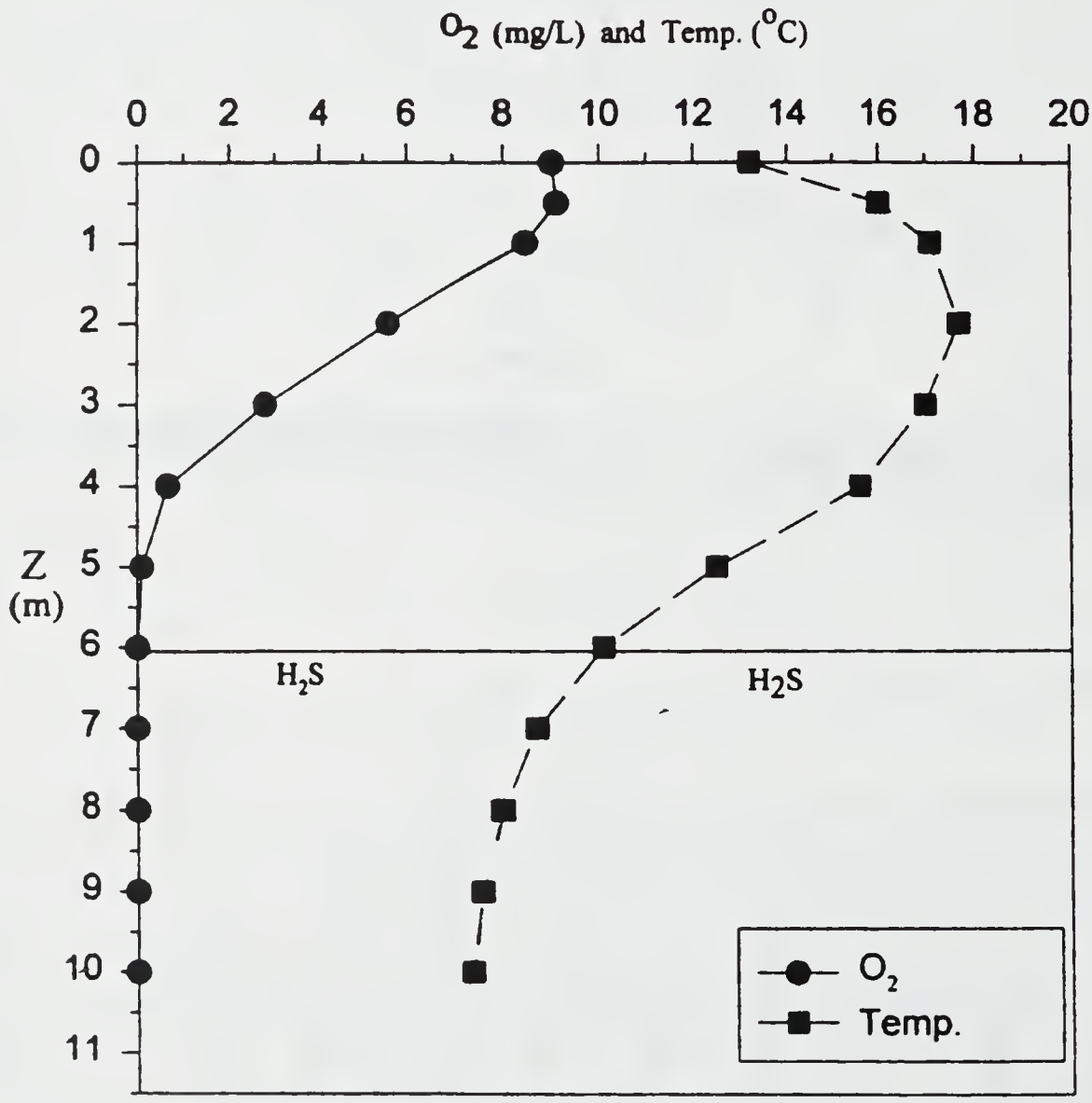

Fig 4 Dissolved oxygen (mg/L) and temperature (°C) in relation to depth (m) on October 4, 1996 at station 1 in Goat Lake.

Biota of Goat Lake

The biotic survey in shallow water less than 3 m deep yielded 36 species of animals and 10 species of plants (Spares 1997). Of the 8 species of molluscs found, 4 are bivalves: the mussels, *Geukensia demissa* and *Mytilus edulis* [L., 1758]; the false quahog, *Pitar morrhuana* [Gould, 1848]; and the American oyster, *Crassostrea virginica*.

Ribbed mussels occurred mainly in the subtidal zone at depths of less than 1.5 m. Ribbed mussels were infrequently found intertidally semi-buried among the roots of *Spartina* sp., but commonly occurred anchored under the undercut ledges of the southern saltmarsh. Subtidally, ribbed mussels occurred as half-buried individuals in sand intermixed with coarse gravel and detritus or aggregated in dense clumps on submerged rocks. Ribbed mussels were found in Goat Lake in waters ranging from 13.8°C to 27°C with salinities ranging from 10.0 o/oo to 28.2 o/oo. Distribution of the ribbed mussels was around the entire shoreline with densities ranging from 12 mussels/m^2 to 460 mussels/m^2 (Fig 1).

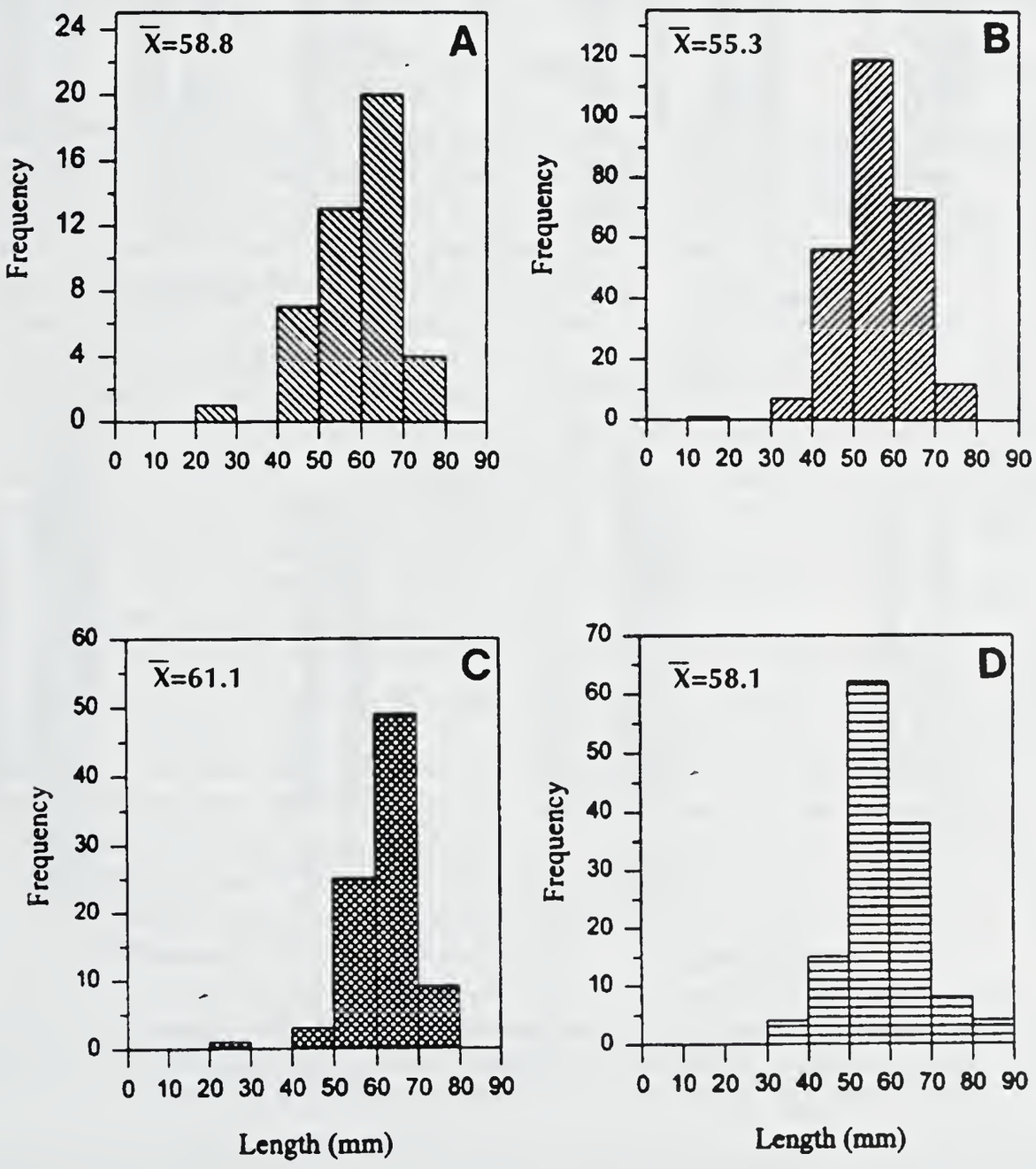

Fig 5 Size histograms of *Geukensia demissa* sampled in Goat Lake during July, 95 (A), August, 95 (B), October, 95 (C), and May, 96 (D).

Shell length of ribbed mussels ranged from 12 to 93 mm. Juvenile ribbed mussels (<30 mm) were rare and were found byssally attached within mussel clumps or as individuals almost completely buried among sand and gravel in the intertidal zone. Individuals half-buried in the subtidal zone tended to be greater than 30 mm. Size histograms determined from samples of mussels displayed a normal distribution centered around a mean shell length of 58 mm with juveniles disjunct from the normal distribution (Fig 5).

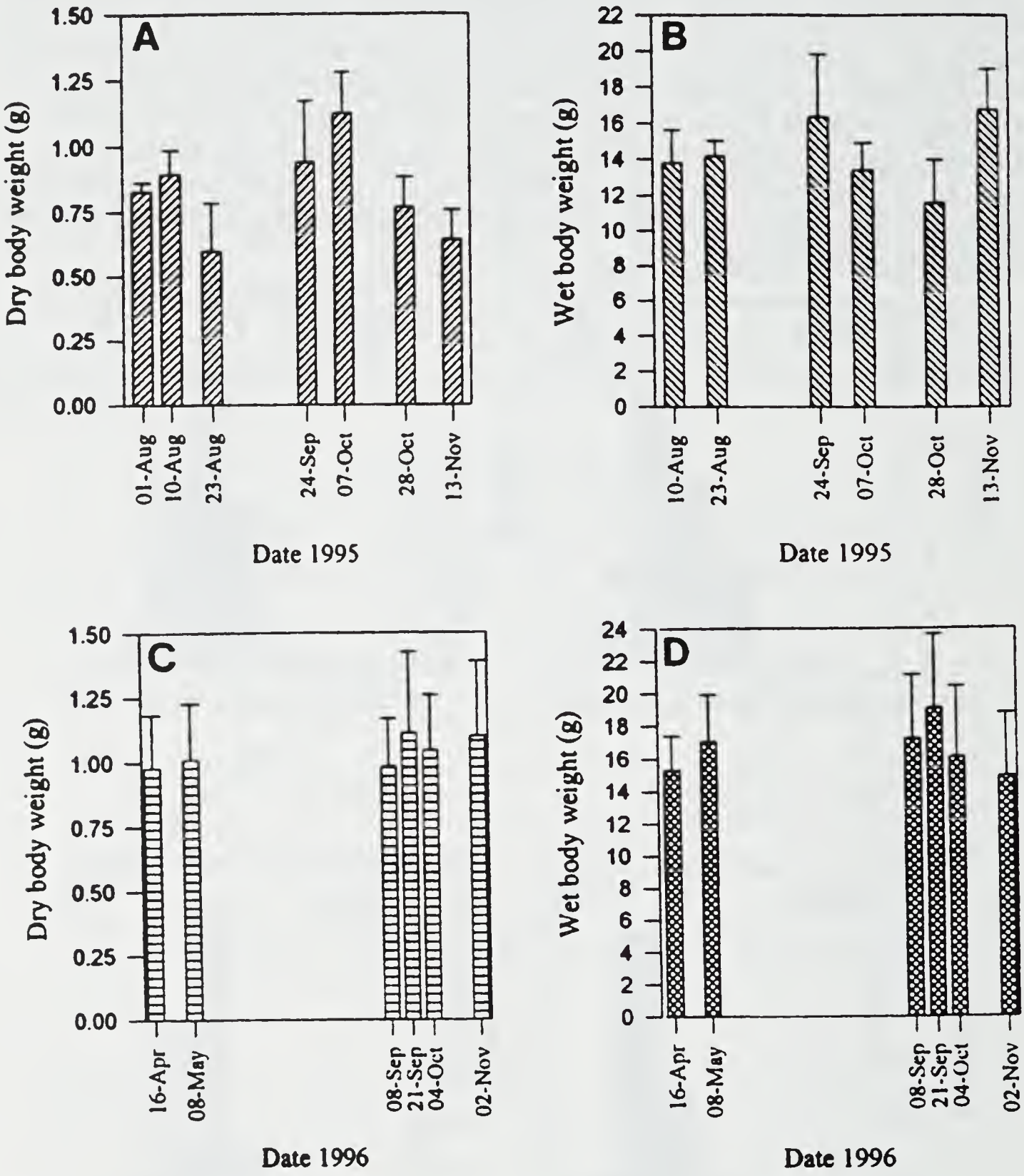

Fig 6 Mean dry body weight (g) (A, C) and wet body weight (B, D) of *Geukensia demissa* for standardized shell length 69-76 mm sampled during 1995 and 65-80 mm sampled during 1996. Horizontal lines are 1 standard deviation of the mean.

Gonadosomatic development of the ribbed mussels was monitored by determining wet and dry body weights of samples standardized by shell length. A standardized shell length of 69-76 mm was chosen (0ne-way ANOVA, P=0.05) for which there was no

statistical significant difference (P=0.480) between the mean shell lengths of each collection during 1995. A significant weight decrease from 0.894 g to 0.295 g (ANOVA/Student-Newman-Keuls, P=0.05) in mean dry body weight (g) occurred between August 10 and August 23, 1995 (Fig 6). Another significant decrease in mean dry body weight from 1.13 g to 0.767 g (ANOVA/Student-Newman-Keuls Method; P=0.05) occurred between October 7 and October 28, 1995. Wet body weight decreased significantly (one-way ANOVA, P=0.05) between September 14 and October 28, 1995 (Fig 6). There was no significant decreased (one-way ANOVA, P=0.05) in wet body weight between August 10 and August 23 or between October 7 and October 28 indicating the mussels probably took in water as gametes were released.

American oysters were found in the south cove of Goat Lake during 1995 cemented onto submerged granite rocks. By 1996, oysters were commonly encountered in shallow water around the periphery of the lake. These oysters were smaller (mean 47 mm) compared to the larger specimens (mean 90 mm) encountered in the south cove suggesting a successful spawning event during 1995.

Discussion

Environmental conditions in Goat Lake are due to a complex combination of factors including its size, inflow characteristics, flushing time, and stratification. Relative depth (Zr) of Goat Lake is 2.26% and volume development (D_v) is 0.358. Since D_v <1.0 (1.0 = a lake with a volume equal to the hypothetical cone) and Zr, is 2.26%; Goat Lake is dominated by the shallows around its periphery.

Water level fluctuation due to tides is minimal, only 5.5 cm on average. The sill in the connecting channel to Mahone Bay restricts inflow and outflow. Seasonal conditions account for the greatest changes in water levels. Highest water levels were recorded during spring runoff and fall rains and lowest during high evaporation and low precipitation in summer. Tidal range was greatest for spring tides, but duration of inflow was longest for spring and neap tides. Neap tides have long duration of inflow due to the fact that the rising tide had a shorter height to surmount the sill. Flushing time (Tully, 1949) ranged from 15.0 days during stratification to 32.4 days during decreased stratification caused by turnovers.

Temperature patterns in Goat Lake show classical summer stratification of a stratified estuary with a thermocline at 3-4 m and the periodic occurrence of mesothermy within the upper 1 m (Fig 2). Since Goat Lake seems to follow the characteristic profile of a dimictic lake, it is inferred that it does undergo two turnovers. Although no direct data was collected to justify this, the water does appear to become more loosely stratified in November and was nearly isothermal in mid-April (Fig 2) indicating possible turnover events in late December and early April. Ice forms over the lake during the winter months indicating possible inverse stratification. If so, one would expect anoxic conditions in the lower saline layer during the winter period also.

Waters with unusual salt stratification sometimes exhibit a vertical temperature profile with the greatest temperature at some depth, suggesting inverse stratification (Fig 4). The layer of salt water underneath the freshwater layer often exhibited warmer temperatures that were sandwiched between colder upper and lower layers. The mesothermal profile was a result of the solar radiation penetrating the upper clear layer to be rapidly absorbed by the upper part of the saline stratum (Cole, 1994). Comparative data between Goat Lake and Mahone Bay provide convincing evidence that Goat Lake is warmer at most times during the year, especially during the spring. Salinity

profiles indicated a highly stratified system with a surface layer of brackish water and a lower saline layer trapped by a sill at the connecting channel to Mahone Bay. Goat Lake could be almost classified as a fjord type estuary with a two-layer flow with entrainment estuarine circulation type (Bowden, 1967). The salinity of the lower layer (Z>1 m) remains relatively unchanged with a small proportion of low-salinity water from the upper layer (z = 0-1 m) entering the layer below. This interface between fresh and saline water is then replaced with an intermediate mixing layer of steep salinity gradient. The deeper saline layer acted as a reservoir of seawater in which circulation was restricted, with the majority of seaward horizontal movement occurring above the halocline.

The odor of hydrogen sulfide in water samples brought up from a depth of 8 m in July 19, 1996 prompted water samples to be analysed for dissolved oxygen. High concentrations of dissolved oxygen, an average of 8.35 mg/L at a depth of 0.5 m, within the upper 3 m of water suggest higher primary productivity compared to Mahone Bay with an average concentration of 8.0 mg/L in the first 2 m of water.

Layers of reduced oxygen generally occur in the ocean at depths below sills in enclosed basins or at depths with minimal horizontal movement. These layers may be accompanied by the production of hydrogen sulfide as in the Black Sea (Cushing and Walsh, 1976). Goat Lake exhibits these characteristics with oxygen depletion occurring in water deeper than 4 m from mid-summer to late fall. The anoxic region correlates with the presence of the thermocline at a depth of 3-5 m (Fig 4).

The anoxic conditions of the deeper layer have resulted from stratification of upper waters, poor tidal flushing, and destruction of one of two connecting channels to adjacent Mahone Bay. Poor tidal flushing is partially related to only one channel connecting the lake to the ocean.

The biota of Goat Lake largely occurs in the shallow waters less than 3 m deep due to the anoxic conditions present in the lower saline layer. Of all the large species identified, molluscs were the most prevalent organisms found (Spares, 1997), but the American oyster and the ribbed mussel were notable since they do not commonly occur within the coastal waters of south and east Nova Scotia (Gosner 1978).

Ribbed mussels are a dominant component of the Spartina zone of salt marsh communities along the east coast of North America south of Canada (Bertness 1980; Brousseau 1984; Lin 1989). North of northern Massachusetts, *Geukensia* is very scarce and mainly occurs subtidally (Franz, 1995). There are records of populations occurring in Minas Basin and Malpeque Bay, P.E.I. (Brousseau, 1982; Bromley and Bleakney, 1985). Goat Lake is the only recorded population of ribbed mussels occurring along the east and south coast of Nova Scotia.

The ribbed mussel is highly eurytopic tolerating temperatures of -22°C to 40°C and salinities of 5 o/oo to 75 o/oo (Bertness, 1980). The conditions experienced by the mussels in Goat Lake falls well within these extremes. Ribbed mussel distribution of northern U.S.A. populations is in dense aggregations at and near the marsh edge (Nielsen and Franz, 1995). In the Branford marsh in Connecticut, mussel densities of 1,500 mussels/m^2 and upwards were recorded (Fell et al., 1982). In Goat Lake, the mussel population is predominantly subtidal clumps due to the low tide range with densities ranging from 12 to 460 mussels/m^2.

The propensity to form dense aggregations on hard and soft substrata is the ribbed mussel's key for success against physical disturbance and predation, particularly in the case of juvenile mussels (Bertness and Grosholz, 1985). In Goat Lake, clumping on rocks decreases predation by the population of green crabs *Carcinus maenas* [L., 1758], suffocation from sediment deposits, and disturbance from winter ice cover.

Major predators of ribbed mussels farther south include the blue crab, *Callinectes sapidus* [Rathbun, 1896] and the mud crab, *Panopeus herbstii* [Milne-Edwards, 1834] which both show a preference to feed on smaller mussels (10-30 mm). *Geukensia*, once it reaches a size of 30-40 mm has increasing immunity to predation due to a thicker shell and firm anchorage in a vertical half-buried position to protect the venerable umbo (Seed 1980). The presence of empty shells littering the lake bottom and the absence of small numbers of mussels ranging in size from 0-40 mm suggests heavy predation. Sampling indicated that immunity to predation is achieved and there is high survivorship in the 50-70 mm length classes (Fig 5).

The juvenile mussels (<30 mm) found within the crevices of clumps and almost completely buried in the intertidal zone suggests both "selective settlement" and "secondary settlement" may occur (Bertness and Grosholz, 1985). "Selective settlement" deals with active settlement around adult conspecifics due to chemical and tactile cues. "Secondary settlement" occurs during the year after metamorphosis involving mobile juveniles (5-10 mm) which can move on average 2.1 cm/day in order to concentrate among adult conspecifics (Bertness and Grosholz, 1985). The advantages of settling among adults involve escaping predation, reducing risk of desiccation and thermal stress, and avoiding sediment burial (Nielsen and Franz, 1995).

Geukensia demissa is a dioecious bivalve that reproduces by broadcast spawning. Monitoring of wet and dry body weight was used to determine gonad development. The ripe stage occurred when dry body weight reached a maximum, and the spent stage was after a sudden decrease in dry body weight. The population of Goat Lake was determined to be self-reproducing as evident by the gonadosomatic monitoring and subsequent occurrence of small juveniles (12 mm). *Geukensia* from New England and Connecticut exhibit a single spawning period from June through September (Borrero, 1987). In Malpeque Bay, P.E.I. during mid-July to August, larvae were reported within the plankton indicating spawning in June to July since the larvae stage lasts approximately one month (Brousseau, 1982). Our results from 1995 indicated the possibility of two separate spawning events, one occurring in mid-August and one in mid-October (Fig 6). These results do not agree with the current literature and sources of error or misinterpretation may be because of the small sample sizes (n = 9-12) collected for gonadosomatic monitoring and the subsequent standardizing which decreased sample sizes still further (n = 6-12). The collecting of small samples was taken as a precautionary measure not to seriously decrease the small population of ribbed mussels in Goat Lake.

Occurrence of temporal variation across the intertidal zone as an approximate two-month delay in reproductive activity caused by diminished nutritional status brought on by reduced feeding time has been established by Borrero (1987). Site-to-site differences in food quantity and quality were identified as the major determinants of gametogenesis and spawning in ribbed mussels (Borrero, 1987). The appearance of two spawning events could be explained by this temporal variation across the population since the samples were taken from different locations within the lake. Perhaps a group of ribbed mussels sampled from a certain part of the lake were experiencing diminished nutritional status which resulted in a two-month delayed spawning period. Oysters, mussels, and other animals may remain closed or cease feeding when adverse conditions are present resulting in poor growth and gonad ripening (Moore, 1958). Ribbed mussels within Goat Lake have been observed to be closed at times when fully submerged, which suggests that nutritional deprivation could be the reason for these two spawning events.

The presence of American oysters was predictable in Goat Lake. Although American oysters do not commonly occur on the east and south shore of Nova Scotia, their range extends as far north as southern Maine with disjunct populations in the Gulf of St. Lawrence and Bras d'Or Lake, Cape Breton Island (Gosner, 1978). This population of adult-sized animals was thought to occur solely in the south cove connected to Mahone Bay, but smaller specimens observed around the periphery of Goat Lake while snorkeling in 1996 indicated that oysters reproduced in Goat Lake. The salinities in Goat Lake fell well within the oyster's tolerance of 5 o/oo to 30 o/oo (Gosner, 1978). The question of how the oysters may have reached Goat Lake was answered by a conversation with a local resident of Goat Lake. Apparently, the oysters were introduced approximately 12 years ago by a person who had some leftover live oysters that would have died. Whether this population is really a result of this introduction or the survival of a natural population like the ribbed mussels will require further study.

There are presumably more marine situations, such as Goat Lake, along the south shore of Nova Scotia where unique environmental conditions enable the survival of these molluscs and/or other warm water species. Because of the uniqueness of each site, a concerted effort should be made to survey them. Many may deserve being placed on the list of protected, natural heritage sites for the province. Unfortunately, the discovery and description of these unique ecosystems has lagged behind comparable terrestrial ones.

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GEOCHEMICAL EVIDENCE FOR THE RECENT CHANGES IN A SALT MARSH, CHEZZETCOOK INLET, NOVA SCOTIA, CANADA

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Sediment cores were collected from the salt marsh located in the West Head of Chezzetcook Inlet, and analyzed to determine the recent changes in geochemistry as a result of both natural and anthropogenic influence. ^{137}Cs dating was used to determine the accretion rates and shows that the sedimentation rates have been slightly higher in the high marsh than in the middle marsh for the last 30 years, probably as a result of increased terrestrial sediment influx. Elemental distribution is mainly related to mineral matter abundance and variety (e.g. mica, halite). However, elevated concentrations of Fe, Ni, Co, Mo and As near the surface of the marsh sequence at the landward edge of the marsh is attributed to anthropogenic input related to the recent road construction, while an elemental enrichment at about 1 m depth is attributed to diagenetic processes, which have resulted in elemental precipitation as sulfides at the boundary between the oxidized and reduced sediment layer.

On a collectioné des carottes de sédiment du marais salé situé à West Head de Chezzetcook Inlet, et on les a analysés en but de déterminer les changements géochimiques dus aux influences naturelles et anthropogéniques. La datation au ^{137}cesium a été usagée pour déterminer les taux d'accrétion, et a demontré que les taux de sédimentation ont été un peu plus élevés dans le haut marais que dans celui du milieu pendant les dernières 30 années, probablement à cause d'un plus grand envahissement de sédiment terrestre. La distribution d'éléments se rapproche surtout à l'abondance et à la variété de matières minérales (par ex., le mica, la halite). Tout de même, les concentrations du Fe, Ni, Co, Mo et As près de la surface de la terre en haut du marais se rapporte à l'entrée anthropogénique pendant la construction récente d'un chemin. L'enrichement d'éléments à un mètre de profondeur est dû aux processus diagénétiques qui ont effectué la précipitation élémentaire de sulfures à la borne entre les couches de sédiment oxydé et réduit.

Introduction

Salt marshes act as natural sinks for fine-grained sediments and associated trace metals, and are also well protected from physical disturbance such as bioturbation; thus they have the potential to preserve an undisturbed record of environmental changes (McCaffrey and Thomson, 1980). Sediment cores from salt marshes have therefore often been used to assess the extent of contamination and to reconstruct the history of pollution in coastal areas (e.g. McCaffrey and Thomson, 1980; Thomas and Varekamp, 1991; Varekamp, 1991; Valette-Silver, 1993; Zwolsman *et al.*, 1993; Cundy and Croudace, 1995; Calloway *et al.*, 1996; Cochran *et al.*, 1998). The stratigraphic record of ^{137}Cs fallout, which provides information about the recent sediment accumulation rates, has also been used successfully in a number of studies to determine lateral variations in salt marsh accretion and their response to natural and anthropogenic influences (e.g. Delaune *et al.*, 1978; Craft *et al.*, 1993; Cundy and Croudace, 1995; Williams and Hamilton, 1995; Calloway *et al.*, 1996; Orson *et al.*, 1998).

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Chezzetcook Inlet is one of the most extensively studied estuaries of the Canadian Atlantic coast, as it provides a record of the coastal evolution and sea-level changes for the past 4000 years (Scott, 1977a; 1977b: Scott, 1980; Scott and Medioli, 1980; Scott *et al.*, 1987; Orford *et al.*, 1991; Carter *et al.*, 1992; Jennings *et al.*, 1993; Shaw *et al.*, 1993; Scott *et al.*, 1995). Investigations of the environmental changes in the last 200 years include studies of the recent evolution of the gravel barrier at Story Head (Orford *et al.*, 1991; 1995), the development of salt marshes at close proximity to the barrier, with a 2000 year long record (Jennings *et al.*, 1993), and the morphological changes in the estuary (Scott, 1980).

However, little is known about the most recent environmental changes in the salt marsh at the head of the inlet. A new road (Highway 107) was constructed across the northern part of the salt marsh in the late 1980's and there was some concern about the impact of road construction on the salt marsh. This paper discusses the vertical and lateral variations in geochemistry in the salt marsh, as a result of natural and anthropogenic influence.

Material and methods

Site description

Chezzetcook Inlet is located about 25 km ENE of Halifax, on the eastern shore of Nova Scotia. The estuary started forming as a result of submergence of the Nova Scotia coast and relative sea-level rise (RSLR) about 4000 years ago (Scott *et al.*, 1995). A drill core in the West Head of the estuary shows the presence of freshwater peat, overlain by a gradational salt marsh sequence, which grades sharply into 10 m thick intertidal mudflats (Scott, 1977a, 1980). The area investigated (44°42'N; 63°15'W) is situated in the West Head (Fig 1), and is mostly an area of middle marsh with steep-sided channels, as shown by the vegetation cover (Scott and Medioli, 1980). The stratigraphic record suggests that salt marsh formation in the West Head of Chezzetcook Inlet was initiated approximately 200 years ago, probably as a result of increased sedimentation related to settlement of European immigrants in the area (Scott, 1980). Road construction in the late 1940's and early 1950's promoted an increase of marsh area in the inlet (Scott, 1980) and probably increased sedimentation rates in the salt marsh in the West Head.

Bedrock geology of the immediate area is dominated by quartzites, gneiss, greywackes and slates of the Goldenville Formation, Cambro-Ordovician age, which is part of the Meguma Group (McBride, 1978). Surface geology consists mainly of Quartzite Till, a stony till derived from local sources (Stea and Fowler, 1979).

Marsh vegetation consists primarily of *Spartina patens*, which is typical of middle marsh, with *Spartina alterniflora* in the lowest marsh elevations. In the high marsh, the vegetation is dominated by Cyperaceae and *Juncus gerardii* (Scott and Medioli, 1980).

Sample collection

Two long cores were taken with a Russian-type auger in the middle marsh (core CH1a; 2 m long) and high marsh (core CH2a; 0.90 m long) in 1991 (Figure 1). In 1993 four surface cores (maximum 0.20 m depth) were taken in the middle (CH1b and CH4) and high (CH2b and CH3) marsh. Cores CH3 and CH4 were taken close to the new highway built in 1985-87. Core CH2b was collected near the western tip of the West Head of Chezzetcook Inlet (same location as core CH2a), and core CH1b was taken on the south side of the median channel in the middle marsh, at the same location as core CH1a (Fig 1).

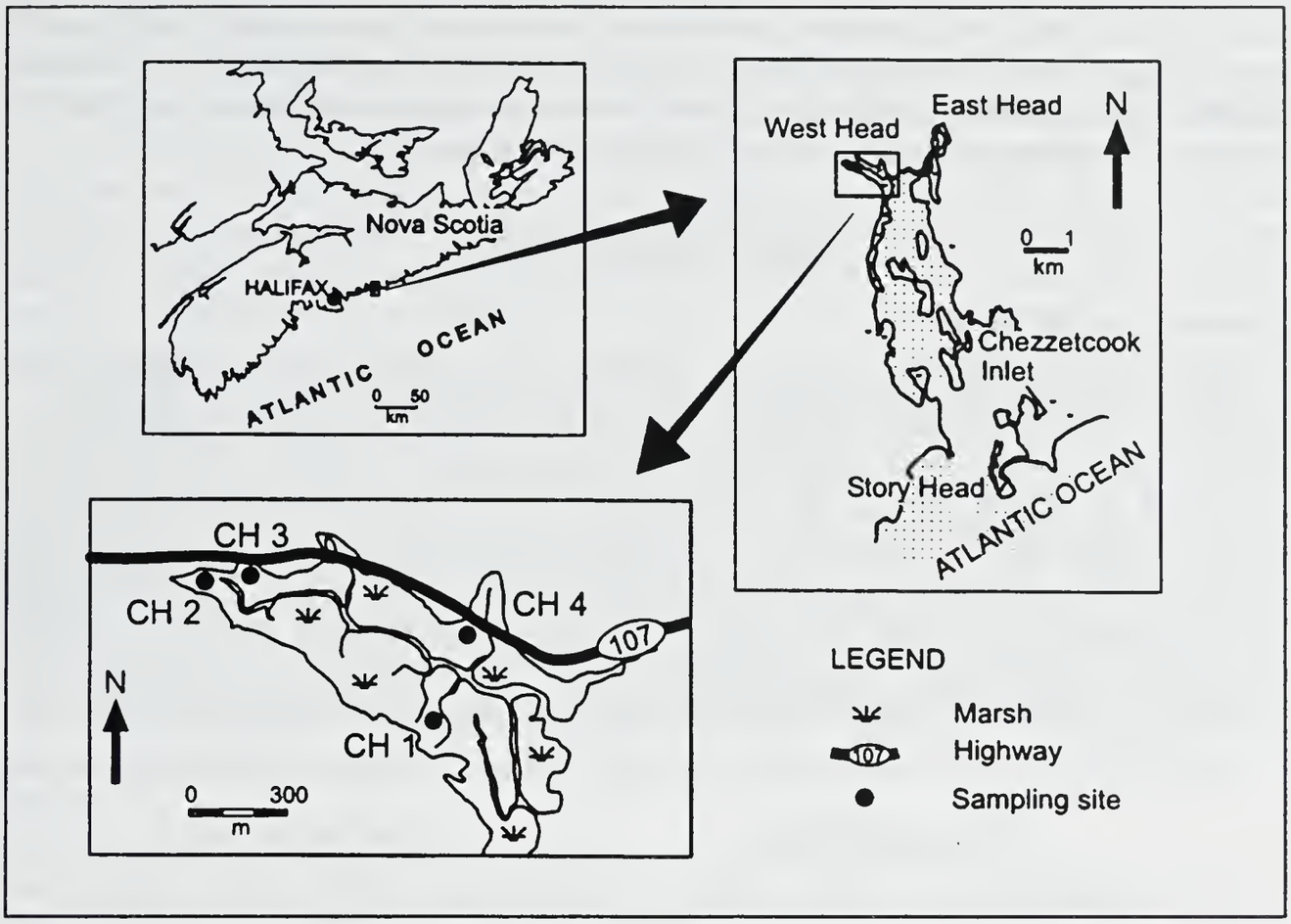

Fig 1 Location map of the salt marsh in the West Head of Chezzetcook Inlet, Nova Scotia, Canada, showing core locations. CH1 indicates the sampling site for cores CH1a and CH1b, while CH2 indicates the sampling site for cores CH2a and CH2b.

Chemical and mineralogical analyses

All samples were dried at 60°C overnight to constant weight, prepared for chemical analysis by crushing using an agate pestle and mortar and then divided into four splits. One split was analyzed by Instrumental Neutron Activation Analysis (INAA). Major and trace elements were determined on a dry weight basis, while the weight loss on ignition (LOI) was determined on a second split by ashing at 1000°C. Mineralogy of a third split of the long cores (CH1a and CH2a) was determined by X-ray diffraction (XRD), and the fourth split from the long cores was also analyzed using a Sulfur-Leco Determinator for total sulfur content.

^{137}Cesium dating

^{137}Cesium (half life = 30 years) is an anthropogenic radionuclide byproduct of nuclear weapon testing or nuclear accidents. It was first recorded in 1953, which corresponds to the onset of deposition in sediments as a result of atmospheric nuclear weapon testing, and peaked in 1963/64, which can be related to a maximum in atmospheric nuclear testing activity in 1962 followed by the Nuclear Test Ban Treaty of 1963 (Carter and Moghissi, 1977). ^{137}Cesium has a strong affinity for clay and fine organic particles and is therefore relatively immobile in sediments (e.g. Tamura, 1964; McHenry *et al.*, 1973).

Samples for ^{137}Cs analysis were counted on a gamma ray spectrometer having a solid state Ge (Li) detector, using the method of Lewis (1974). Concentrations of ^{137}Cs are reported as picocuries per gram (pCi/g) of dried sediment. Counting errors were about 10% and concentrations of up to 3.2 pCi/g were measured.

Results and discussion

Salt marsh accretion

Core CH2b provides the best profile of ^{137}Cs concentration, as it resembles other fallout records from modern environments and the 1964 ^{137}Cs fallout peak is resolved (Fig 2). A maximum concentration of 3.2 pCi/g is recorded. Concentrations of ^{137}Cs in core CH3 are significantly lower and it appears that neither the fallout peak nor the onset of fallout has been recorded. This might indicate a higher sedimentation rate, which could be expected due to the proximity of the new road, but the slightly lower ^{137}Cs concentrations might also indicate dilution by increased sediment supply. Bioturbation and mixing are sometimes cited as the cause for low ^{137}Cs concentrations, and they can not be excluded. Post-depositional transport of ^{137}Cs through the sediment

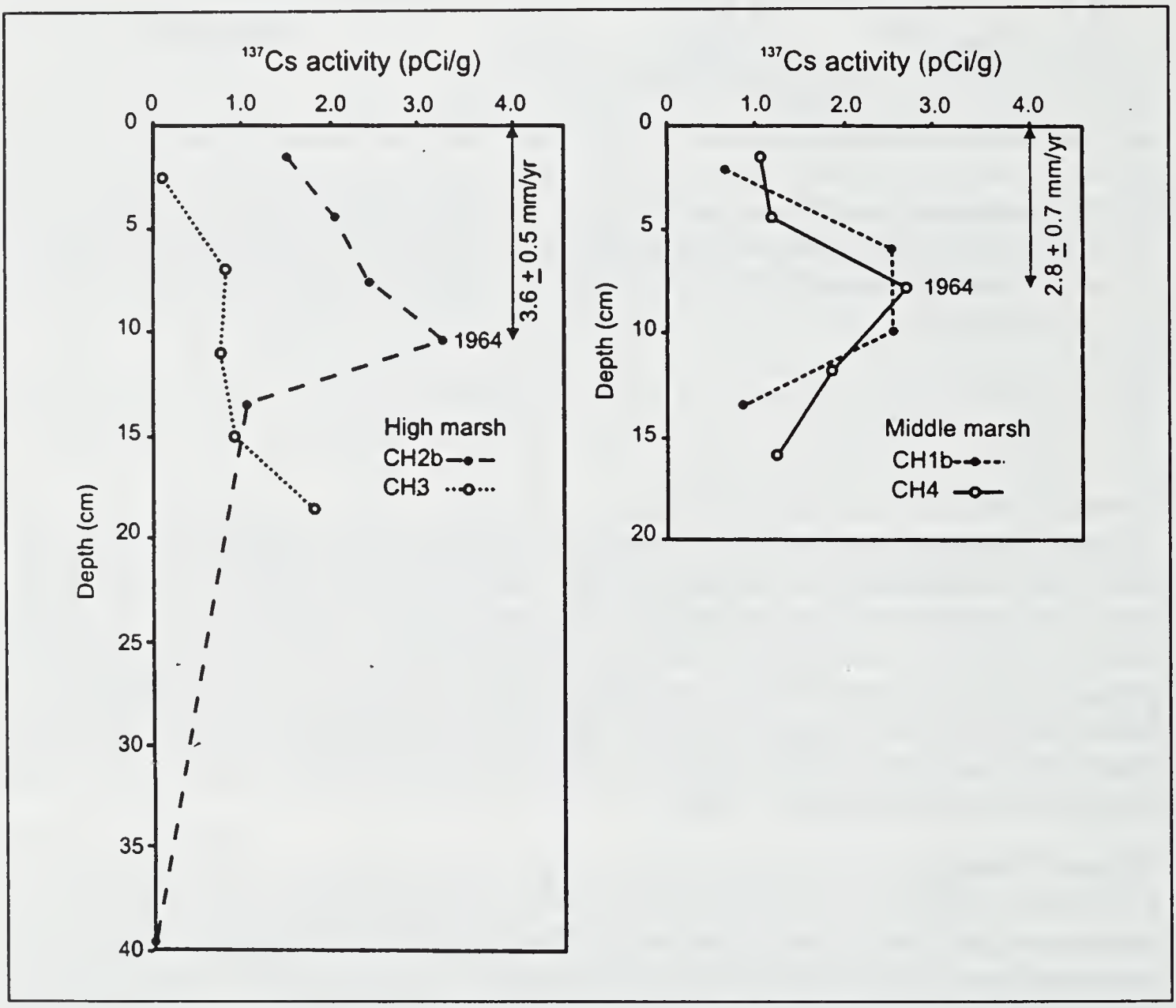

Fig 2 Distribution of ^{137}Cs with depth in cores CH1b, CH2b, CH3 and CH4, Chezzetcook Inlet. Estimated accretion rates are shown for the period 1964-1993. See Fig 1 for core sampling locations. Cores CH1b and CH2b were taken at sampling sites CH1 and CH2, respectively.

column via porewater diffusion or advection has also been reported (Ritchie and McHenry, 1990) and could account for the ^{137}Cs profile in core CH3.

The fallout profiles of cores CH1b and CH4 are more poorly resolved than that of core CH2b, but the peak fallout can still be resolved, in particular for core CH4, with a maximum ^{137}Cs concentration of 2.6 pCi/g (Fig 2). The data also suggest that the accretion rates show little variation between the south side and the north side of the salt marsh, the latter being at close proximity to the new highway. As it is not certain whether the onset of fallout in 1954 is detected in any of the cores, only the peaks in activity are used for determining the mean sediment accumulation rate for the period 1964-1993.

The depth of the fallout peak in cores CH1b, CH4 and CH2b suggests an estimated mean accretion rate of 2.8 mm/y in the middle marsh and 3.6 mm/y in the high marsh for the last 30 years. Data obtained from core CH3 are not considered here, due to possible mixing and post-depositional transport of ^{137}Cs. These data suggest that the accretion rates might be slightly higher in the high marsh than in the middle marsh. Previous studies have suggested that sedimentation rates are usually greater in the lower marsh than in the high marsh, due to more frequent flooding and greater sediment input (e.g. Thomas and Varekamp, 1991). However, in the present study, there might be an additional terrestrial sediment influx due to surface runoff and road building in the high marsh area, which could exceed the sediment input from tidal flooding (Chagué, 1994).

Sediment accumulation rates in the salt marsh also slightly exceed the mean rate of relative sea-level rise (RSLR) for the last 1000 years, which is 2 mm/y (Scott *et al.*, 1995). Evidence for the last 200 years also suggests that accretion rates have exceeded RSLR, as the salt marsh in West Head of Chezzetcook Inlet has evolved from low to high marsh (Scott, 1977a; 1980). Increased terrestrial sediment input and surface runoff caused by human activity is likely to have contributed to the slightly higher sediment accumulation rate. Although the number of cores investigated is limited, this study suggests that the recent road construction does not appear to have resulted in a considerable increase in sedimentation rate on the north side of the salt marsh.

Geochemistry and mineralogy

Weight loss on ignition (LOI) averages 42% and 41% in cores CH1a and CH2a, respectively (Fig 3). Sampling at finer intervals in the shallow cores shows that LOI decreases from the surface (maximum of 77%) to 15-20 cm depth (minimum of 37%) and averages 44% (Chagué, 1994). The higher LOI at the surface is attributed to the abundance of fresh plant material, while the decrease with depth is due to degradation of organic material and trapping of fine inorganic material by the marsh vegetation.

The distribution of Al, Mn, K and Mg in cores CH1a and CH2a is similar and shows a negative relationship with LOI distribution (Fig 3). This suggests that these elements are associated with the inorganic fraction of the marsh sediments, mainly in clay minerals, such as mica (illite) and chlorite, as well as in feldspars (as determined by XRD; Chagué, 1994).

Sodium and Cl concentrations show a marked increase toward the surface in core CH1a, which is attributed to the presence of halite. XRD analysis of the core reveals up to 16% halite at the surface of core CH1a, while the mineral is absent or only present in small amounts in the subsurface sediments and in core CH2a. Halite probably reflects important evapotranspiration and resulting oversaturation of Na and Cl at the marsh surface during drought periods between tidal flooding. The absence of halite in almost all other samples analyzed by XRD is attributed to dissolution *in situ* as a result of flushing or capillary action. Freshwater runoff is also more significant at the western tip of West Head (location of core CH2a), and thus enhances dissolution of halite.

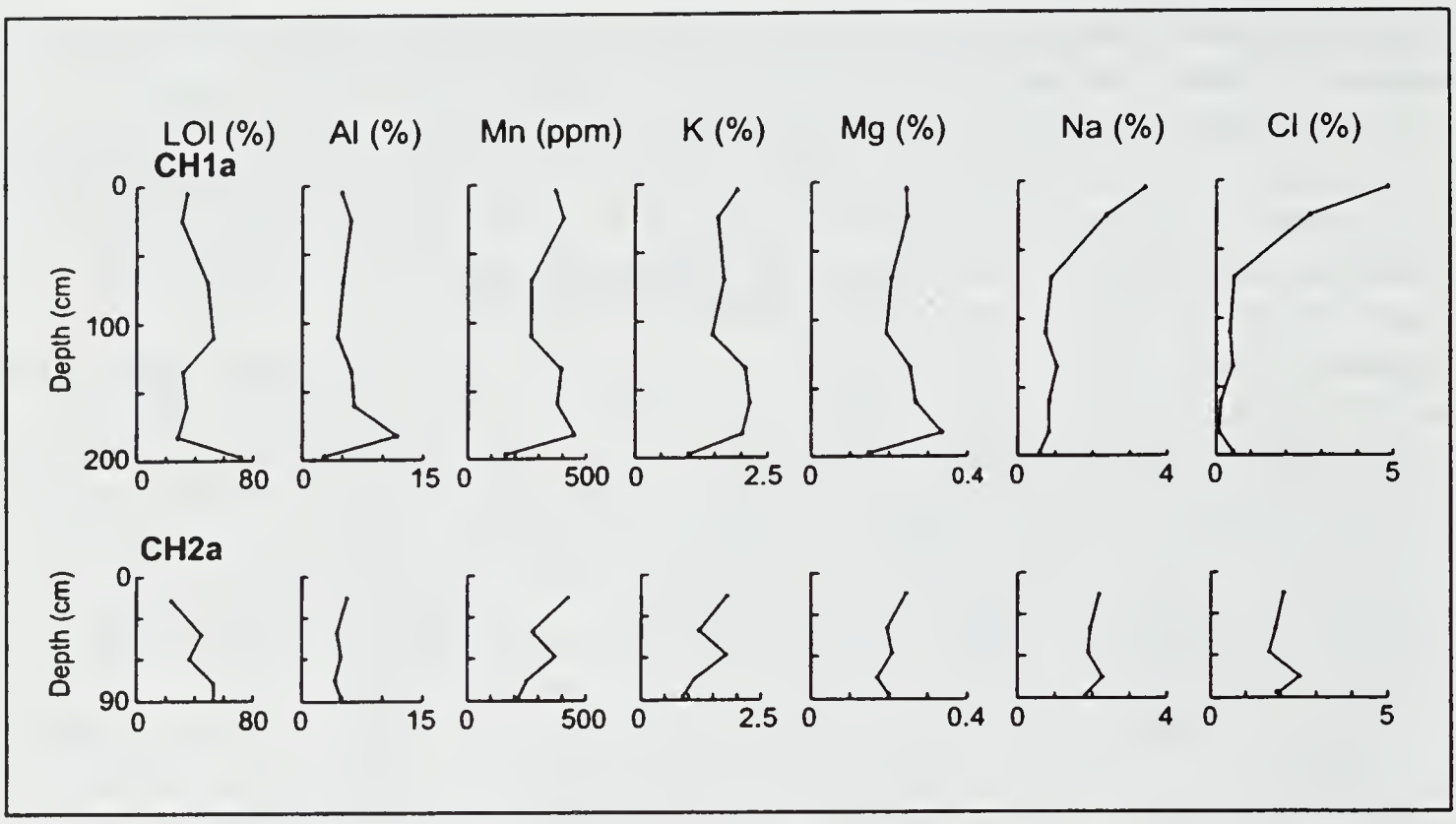

Fig 3 Weight loss on ignition (LOI), aluminium (Al), manganese (Mn), potassium (K), magnesium (Mg), sodium (Na) and chlorine (Cl) distribution in cores CH1a (middle marsh) and CH2a (high marsh). See Fig 1 for core sampling locations. Cores CH1a and CH2a were taken at sampling sites CH1 and CH2, respectively.

Iron concentrations average 3.4% in the core taken in the middle marsh (CH1a) and 1.9% in the core taken in the high marsh (CH2a). Fe concentrations in salt marsh sediments have been interpreted as being representative of the abundance of fine-grained matter in the marsh and are thus being used as a proxy for flooding frequency (Varekamp, 1991; Thomas and Varekamp, 1991; Chagué-Goff and Goff, 1999; Goff and Chagué-Goff, 1999), since Fe occurs mainly as fine-grained oxides in coastal and estuarine environments (Coonley *et al.*, 1971). Low and middle marsh areas are flooded more frequently than high marsh areas, and thus trap more fine-grained material. Therefore, the higher Fe content measured in the middle marsh than in the high marsh can be interpreted as a result of more frequent tidal flooding. In core CH1a, there is an enrichment of Fe, As, Co, Mo and S at a depth of 1.00-1.20 m (Fig 4), which does not coincide with a decrease in LOI (Fig 3) and thus can not be attributed solely to an increase of the mineral matter content in that particular interval. The Fe-rich band occurs at the upper boundary of the low marsh with the middle marsh (this delineation is based on macrophyte remains and foraminifera assemblages; Scott, 1977a; 1980). Enrichments of Fe and other metals have been found at the boundary between oxidizing and reducing conditions in tidal marsh sequences, where mobilization and reprecipitation as sulfides occur (e.g. Zwolsman *et al.*, 1993). McCaffrey and Thomson (1980) and Cochran *et al.* (1998) have also reported the presence of iron sulfide phases associated with metals. The coincidence of the Fe and S peaks is attributed to precipitation of Fe sulfides due to sulfate reduction (e.g. Zwolsman *et al.*, 1993). Pyrite was the dominant S mineral fraction determined by XRD, and microscopic observations revealed pyrite occurring mostly as framboids in association within the cortex of rootlets and rarely as small anhedral crystals (Chagué, 1994). Such an association of framboidal pyrite with plant rootlets has been frequently reported in salt marsh environments (e.g. Cohen *et al.*, 1983; Altschuler *et al.*, 1983; Oenema, 1990).

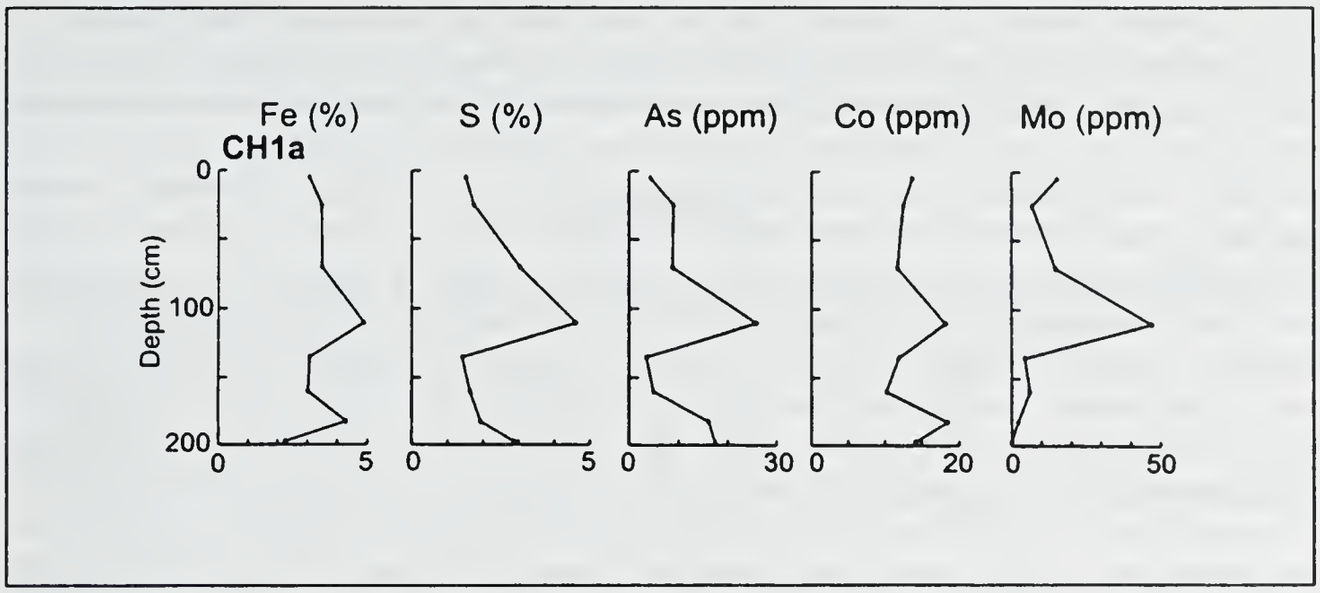

Fig 4 Iron (Fe), sulfur (S), arsenic (As), cobalt (Co) and molybdenum (Mo) distribution in core CH1a (middle marsh). Note the enriched interval at 1.00-1.20 m depth. Core CH1a was taken at sampling site CH1 (see Fig 1 for sampling location)

Previous studies also show that S and Fe are commonly correlated, as Fe-rich sediments are more likely to fix S than Fe-poor sediments (e.g. Thomas and Varekamp, 1991; Chagué-Goff and Goff, 1999). Thomas and Varekamp (1991) also report similar correlations in Fe-rich bands (except for As) and attribute this increased supply of trace elements in the pre-pollution period (before input of anthropogenic contamination) to an increase in flooding frequency. In the present study, As, Mo and Co are probably derived from the Goldenville Formation slates, which provide a local source for these elements (Graves and Zentilli, 1988). Their elevated concentrations in the interval at 1.00-1.20 m in core CH1a can be attributed to their association and precipitation as sulfides in the upper boundary of the low marsh sequence.

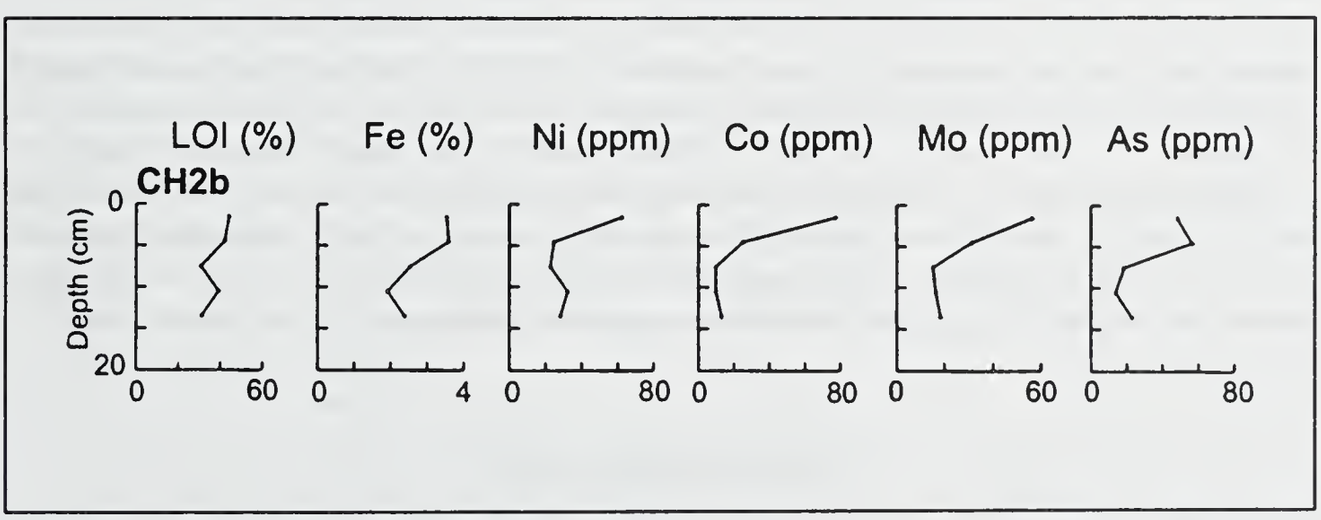

Fig 5 Weight loss on ignition (LOI), iron (Fe), nickel (Ni), cobalt (Co), molybdenum (Mo) and arsenic (As) distribution in core CH2b (high marsh). Core CH2b was taken at sampling site CH2 (see Fig 1 for sampling location).

In three of the four shallow cores, Fe concentration decreases with depth, whereas LOI increases, thus suggesting that Fe distribution can be explained in terms of mineral matter abundance (Chagué, 1994). In the fourth core, CH2b, Fe exhibits an enrichment in the top 6 cm, which correlates with an increase in As concentration, while Ni, Co and Mo concentrations show a marked increase in the top 3 cm (Fig 5). Bearing in mind the rates of accumulation inferred from ^{137}Cs analysis (ca. 3.6 mm/y), the top 3 cm of core CH2b appear to have accumulated in approximately 8 years. This corresponds with the time frame between the start of the road construction (1985) and the time of sample collection (1993). Core CH2b was taken near the western tip of West Head, where freshwater runoff dilutes seawater, as indicated by low salinity values (Scott, 1977a; 1977b). Thus, it is probable that Fe transported in freshwater runoff precipitated at the head of the salt marsh, as Fe colloids transported in freshwater runoff have been shown to flocculate when entering the brackish environment (Boyle *et al.*, 1977). The enrichment of As, Ni, Co and Mo in the Fe-rich interval can be attributed to the strong affinity of these elements for Fe-oxides and hydroxides (e.g. Lee, 1975). These elements were probably released in dust and runoff in association with the recent road construction (e.g. heavy equipment, Goldenville Formation slate used as road fill), transported into the salt marsh by freshwater runoff, and precipitated with Fe-oxides when entering the brackish environment. Elevated concentrations were not found in cores CH3 and CH4, which are located approximately 20 m from the highway. Therefore it is suggested that contamination associated with the most recent road construction is fairly localized in the salt marsh.

Conclusions

Variations in accretion rates, geochemistry and mineralogy in Chezzetcook Inlet salt marsh were determined using ^{137}Cs dating, INAA, Sulfur-Leco and XRD. The depth of the peaks in ^{137}Cs activity was used to estimate the accretion rates and suggests that they are slightly higher in the high marsh (CH2b, CH4 - 3.6 mm/y) than in the middle marsh (CH1b - 2.8 mm/y), possibly as a result of increased terrestrial input related to road construction in the area. Accretion rates are also slightly higher than the rate of relative sea level change.

Elemental distribution in the sediment cores is controlled by both natural and anthropogenic processes. Mobilization and reprecipitation of trace elements as sulfides occur at the boundary between the oxidized and reduced sediment layer, in the upper part of the low marsh sequence, and coincide with the presence of abundant pyrite framboids. The occurrence of halite at the surface of the middle marsh accounts for the elevated concentrations of Na and Cl. Aluminum, Mn, K, Mg on the other hand are probably present in mica (illite), chlorite and feldspars. Increased concentrations of Fe, Mo, Ni, As and Co in the top layer of the marsh sequence at the landward edge of the salt marsh are attributed to anthropogenic influence as a result of road construction. However, this study suggests that the impact of road construction on the salt marsh is limited in extent.

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SOME ASPECTS OF THE ECOLOGY AND PHYSIOLOGY OF FUNGI ISOLATED PREDOMINENTLY FROM THE WOOD OF TREES OF THE NORTHERN TEMPERATE FOREST

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About 3800 cultures of fungi held in five collections in North America and one in Russia have been selected and reviewed on the basis of their woody substrates, and when these substrates were trees, the geography of their isolations. Fifty eight tree genera were recorded as substrates, but only 17 of these, commonly used for timber, were responsible for 10 or more isolations of fungi. The cultures were collected in 29 countries of which 21 were in the Northern Hemisphere north of latitude 45°. The production of wood-degrading enzymes by 69 of these fungal genera is reviewed as is their ability to produce colored or potentially colored metabolites. Work on the possible use of endophytic fungi as control agents against the invasion of wood by pathogens is summarized. This data and the physiological chemistry supporting it is supported by 408 references to the original literature.

Environ 3800 cultures de champignons détenues dans six collections, cinq de l'Amérique du Nord et une de la Russie, ont été choisies puis examinées selon leur substrat ligneux. La géographique des isolats a aussi été examinée lorsque le substrat était un arbre. Cinquante-huit genres d'arbres ont été enregistrés comme substrats. Seulement 17 d'entre eux, souvent employés comme bois d'oeuvre, servaient de substrat de dix champignons ou plus. Les cultures provenaient de 29 pays différents dont 21 se situaient dans l'hémisphère Nord, c'est-à-dire au nord du 45 ième parallèle. Soixante-neuf genres de champignons ont été examinés quant à leur capacité de produire des enzymes qui dégradent le bois et des métabolites colorés ou potentiellement colorés. Un résumé des études portant sur l'utilisation potentielle des endophytes pour lutter contre l'invasion du bois par des pathogènes est présenté. Ces données ainsi que la chimie physiologique sous-jacente sont appuyées par 408 citations d'études scientifiques.

Introduction

Wood is almost ubiquitous in the vascular plant kingdom and its use by *Homo sapiens* is similarly common. It is extraordinarily durable - for example the oak gates of New College, Oxford were made in the late fourteenth century (Woolley, 1975) and an examination of their quarter-sawn panels reveals that the tree from which they were cut was at least 500 years old.

Despite this history much remains to be learnt about this valuable commodity. For example the pigments present in the New College gates are of unknown composition, so far as we are aware and it is now known that many vascular plants are lichenogenous. There are therefore, many interesting botanical problems in this field and the aim of this review is to draw attention to some of them.

In the last 15 years or so several collections of fungi have made their holdings available in machine readable form (Brewer *et al.*, 1989). This information is of great value to those seeking live cultures for their work and for students of botanical ecology and taxonomy, because most of these organisms have been isolated by professional mycologists whose taxonomic assignments have been scrutinized by experts in the various taxonomic families. In addition, accurate descriptions of the place and nature of the substrates are often available.

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The review is divided into three sections. The first describes methods used to select the cultures and this provides a description of the fungi that have been isolated from living trees and from processed wood. Next some aspects of the physiology of these fungi are reported, in particular their ability to degrade cellulose and lignin, and their production of colored or potentially colored metabolites. Finally the potential use of endogenous or endomycorrhizal species to control invasion of wood by exotic organisms is critically reviewed.

Methods

The taxonomic, substrate and geographical data on which this review is based has been collected from the mycological catalogues of Agriculture Canada, Ottawa, K1A 0C6 (1989, 7925, DAOM), the Canadian Forestry Service in Fredericton, New Brunswick, E3B 5P7 (1986, 642, FSC) and Edmonton, Alberta, T6H 3S5 (1987, 652, NOF), Forintek Canada Corp., Ste.-Foy, Québec, G1P 4R4 (1993, 2187, FTK), the VKM database, Russian Academy of Sciences, Pushachino, 142292, Russia (1995, 2525, VKM) and the American Type Culture Collection, 12301, Parklawn Drive, Maryland, USA, 20852 (1996, 21162, ATCC). The data in parentheses indicates in the order, the year the data was last updated by us, the number of cultures held on that date (with some editing) and the acronym used henceforth for each collection. The data sent to us by the Russian and United States Collections was converted into the same format (Brewer *et al.*, 1989) as the Canadian Collections. The data was scanned using simple PASCAL or BASIC programming and manually (using such utilities as Microsoft WORD) in the substrate field for wood and wood-products using the following key words: bark, board, branch, chips, log, lumber, plank, pole, post, sawdust, stump, timber, trunk, twig, veneer. All cultures isolated from one or more of these substrates were selected and written onto a separate file (NOIDWOOD) which was then pruned of all duplicate entries e.g. where the same culture was held in different collections.

The data in all of the collections except that of ATCC (see below) were also scrutinized for substrates recorded either as the vernacular name or the binominal name of trees, even though classification in the latter case was only at the genus level. The common names were translated as far as possible into binominal names, often arbitrarily though consistently choosing between synonyms. The resulting file (WODFUNG) was then pruned to leave only one culture of a fungus isolated from the same substrate, in the same geographical area and at almost the same time. In this selection, priority was given to cultures residing in DAOM, FSC and NOF collections. This file was then separated into three parts: the first (TREWODFG) was assembled from fungi that had been isolated from trees and from wood products (i.e. from the NOIDWOOD file). There were 929 culture records on this file. The second file (TREEFG) consisted of 1324 cultures from fully classified trees not on the TREWODFG file and the third part (TREEFGEN) was a list of 1228 fungi absent from the TREWODFG and TREEFG files that were from trees that had been classified only to the genus level. Finally the NOIDWOOD file was purged of those fungal cultures that appeared in the TREWODFG collection, leaving 381 cultures. In all cases isolations from leaves and leaf surfaces were rejected.

The files TREWODFG and TREEFG were augmented in the following way. The fungal culture names and species from the same genera that were found on wood substrates in the ATCC were scrutinized for isolations from woody parts of fully characterized trees, they were then added to either the TREWODFG or the TREEFG files as appropriate, when the fungus was not already present.

The production of cellulases and other wood degrading enzymes by the fungi in the four working files (NOIDWOOD, TEWODFG, TREEFG, and TREEFGEN) was surveyed by consulting the following sections of Biological Abstracts after Vol. 52; 1971: systematic botany (fungi); ecology (general & plant); phytopathology (disease control, fungal diseases & general); plant physiology (enzymes) and soil microbiology. These sections also provided references for other parts of this review. The general subject indices of Chemical Abstracts (1909-1998) were searched under the headings: fungi (& where appropriate, their genera and species names), mycology, microbial chemistry and fermentations. References for fungal metabolites were obtained from the "mycotox" file updated to the end of 1998 as described (Brewer *et al.*, 1978) and also the following databases: BIOSIS previews; AGRICOLA, MEDLINE and TOXLINE. The four files NOIDWOOD, TREWODFG, TREEFG, TREEFGEN, and the updated mycotox file are available from the Librarian of the Institute.

All calculations and compilations were done using algorithms written by us mainly in PASCAL or BASIC mounted on Macintosh or IBM personal computers. These programs are routine but are available for checking purposes from the authors.

Results

Diversity of tree and fungal species studied

The total number of cultures held in the six collections examined was 35393 but this was reduced to 381 for the NOIDWOOD file; to 929 for TREWODFG, 1324 for TREEFG and to 1228 for TREEFGEN, a total of 3862.

The fungi in TREWODFG consisted of 255 species and these are given in Table I together with 49 other fungi found on trees and wood products where the tree(s) were classified only at the genus level. One hundred and forty one genera were represented in the 255 species in TREWODFG but 43 of these occurred once and a further 26 twice. Twenty six fungal genera were present from more than 10 substrates, these were (in order of prevalence; number of isolations in parentheses): *Trichoderma* (51); *Poria* (50); *Tyromyces* (41); *Peniophora* (39); *Pleurotus* (33); *Fomitopsis* (30); *Coniophora* & *Phellinus* (27); *Phialophora* (25); *Coriolus* & *Hirschioporus* (22); *Fomes, Polyporus* & *Stereum* (19); *Anthrodia, Pycnoporus* & *Sistostrema* (17); *Gloeophyllum* & *Hericium* (16); *Aureobasidium* & *Ganoderma* (15); *Pholiota* (14); *Chondrostereum* (13); *Scytinostroma* & *Serpula* (12) and *Irpex* (10). At the species level 21 fungi were obtained in more than 10 isolations, on the basis of genus these were (number of species and number of isolations in parentheses): *Trichoderma* (3, 35); *Poria* (2, 34); *Phialophora* (2, 23); *Coniophora puteana* (23); *Fomitopsis pinicola* (21); *Hirschioporus abietinus* (17); *Phellinus pini* & *Coriolus versicolor* (16); *Aureobasidium pullulans* (15); *Chondrostereum purpureum* (13); *Pleuotus ostreatus, Scytinostroma galactinum* & *Sistostrema brinkmannii* (12); *Hericium americanum* & *Tyromyces balsameus* (11); *Irpex lacteus* & *Pycnoporus cinnabarinus* (10). The tree species from which these fungi were isolated were also concentrated among a few genera - as indicated in Table I. Thus although 44 tree genera were recorded as substrates, 22 were reported only once or twice (32 isolations altogether) whilst 12 genera were reported as substrates more than 30 times and these accounted for 832 isolations or 89.7% of all those on file TREWODFG. These 12 genera were (isolations from in parentheses): *Pinus* (182); *Picea* (120); *Betula* (87); *Populus* (79); *Abies* (67); *Acer* (61); *Pseudotsuga* (52); *Tsuga* (42); *Thuja* (40); *Fagus* (36); *Quercus* (36) and *Ulmus* (30).

Table I Fungi[1] isolated from the woody parts of trees and also from wood derived therefrom*

Fungal binominal name[2]	Substrate Trees
ACROGENOSPORA SPHAEROCEPHALA	Fagus sylvatica; Pseudotsuga taxifolia
ALTERNARIA TENUIS	Abies balsamea; Betula alleghaniensis; Picea mariana; Pinus contorta; Pinus resinosa Populus trichocarpa
AMAUROASCUS AUREUS	Cryptomeria japonica
AMPHISPHAERIA INCRUSTANS	Acer rubrum
ANTRODIA ALBIDA	Acer rubrum; Cedrus deodora
ANTRODIA SERIALIS	Picea abies; P. glauca; P. mariana; P. sitchensis; Pinus excelsa; P. strobus; P. sylvestris Pseudotsuga menziesii
ANTRODIA SINUOSA	Picea mariana; Pinus banksiana; Pseudotsuga menziesii; Tsuga canadensis
ANTRODIA VARIIFORMIS	Picea engelmanni; P. mariana
ASPERGILLUS FUMIGATUS	Ulmus americana
ASPERGILLUS NIGER	Castanea equina (?Aesculus hippocastanum)
ATHELIA FUSCOSTRATUM	Pinus banksiana; P. contonta; P. strobus
AUREOBASIDIUM PULLULANS	Acer saccharum; Betula lutea; B. papyrifera; Pinus banksiana; P. contorta; P. monticola Pinus resinosa; P. strobus; Populus tremuloides; Pseudotsuga menziesii; Thuja plicata
BEVERWYKELLA PULMONARIA	Fagus sylvatica
BISPORA BETULINA	Pinus banksiana; Thuja occidentalis
BJERKANDERA ADUSTA	Acer saccharum; Betula alleghaniensis; B. papyrifera; Fagus grandifolia; Pinus contorta Populus grandidentata; P. tremuloides; P. trichocarpa
CALOCERA CORNEA	Acer sp.; Populus sp.
CALOCERA VISCOSA	Abies balsamea; Pseudotsuga menziesii
CEPHALOASCUS FRAGRANS	Betula alleghaniensis; Pinus banksiana; P. resinosa; P. strobus; Pseudotsuga menziesii Tsuga heterophylla
CERATOBASIDIUM CORNIGERUM	Pinus radiata
CERATOCYSTIS COERULESCENS	Picea abies
CERATOCYSTIS MULTIANNULATA	Pinus sp.
CERIOSPOROPSIS HALIMA	Pinus ponderosa
CHLOROCIBORIA AERUGINOSA	Populus tremuloides
CHONDROSTEREUM PURPUREUM	Abies balsamea; Alnus rubra; Betula alleghaniensis; B. lutea; B. papyrifera; Pinus banksiana Populus balsamifera; P. grandidentata; P. trichocarpa; Pseudotsuga taxifolia; Sorbus americana Ulmus americana
CLADOSPORIUM CLADOSPORIOIDES	Pinus resinosa; Populus tremuloides
CLADOSPORIUM RESINAE	Abies balsamea; Pinus resinosa
CLAVARIOPSIS BULBOSA	Tamarix aphylla
COLLYBIA DRYOPHILA	Populus sp.
CONIOPHORA ARIDA	Abies basiocarpa; Picea orabes; Pinus resinosa; P. rigida; Quercus rubra

Table 1 *continued*

CONIOPHORA PUTEANA	Abies balsamea; Acer saccharum; Betula lutea; Eucalyptus marginata; Larix sibirica; Picea canadensis; P. glauca; P. mariana; Pinus banksiana; P. excelsa; P. strobus; Prunus serotina; Pseudotsuga menziesii; Quercus borealis; Thuja plicata; T. canadensis
CORDANA PAUCISEPTATA	Carpinus betulus; Picea abies
CORIOLOPSIS GALLICA	Populus trichocarpa
CORIOLOPSIS OCCIDENTALIS	Pinus sp.
CORIOLUS VERSICOLOR	Acer saccharum; Alnus rubra; Betula alleghaniensis; B. lutea; B. papyrifera; Castanea dentata Fagus americana; F. grandifolia; Populus tremuloides; Pseudotsuga menziesii; Quercus alba Quercus borealis; Q. robus; Thuja plicata; Tilia americana
CORIOLUS ZONATUS	Alnus incana; Populus papyrifera; P. tremula; P. tremuloides; Salix caprea; Thuja plicata
CORTICIUM CREMORICOLOR	Quercus sp.
CORTICIUM LAEVE	Abies balsamea
CORTICIUM VELLEREUM	Acer rubrum; A. saccharum; Populus balsamifera; Ulmus americana; U. fulva; U. pumila
CREPIDOTUS MOLLIS	Fraxinus excelsior; Fagus sylvatica
CYATHUS STRIATUS	Quercus sp.
CYLINDROBASIDIUM EVOLVENS	Abies balsamea; Acer saccharum; Betula alleghaniensis; Picea mariana; Populus tremuloides Thuja occidentalis
CYLINDROCARPON DESTRUCTANS	Prunus cerasus
CYPTOTRAMA ASPRATA	Pinus sp.
CYSTOSTEREUM MURRAII	Acer saccharum; Betula alleghaniensis; B. lutea; B. papyrifera
DACRYMYCES CAPITATUS	Quercus sp.
DACRYMYCES PALMATUS	Abies balsamea
DACRYOBOLUS SUDANS	Alnus glutinosa
DACRYOPINAX SPATHULARIA	Malus sp.
DAEDALEA QUERCINA	Quercus rubra
DAEDALEOPSIS CONFRAGOSA	Acer spicatum; Betula lutea; B. papyrifera
DALDINIA CONCENTRICA	Betula lutea; B. papyrifera
DATRONIA MOLLIS	Acer sp.
DENDRYPHIOPSIS ATRA	Betula papyrifera
DENTIPELLIS DISSITA'	Fagus sp.
DIPODASCOPSIS TOTHII	Fagus sylvatica
DIPODASCUS AGGREGATUS	Pinus resinosa; P. strobus
EPICOCCUM PURPURASCENS	Abies amabilis; Picea glauca; Pinus strobus; Populus tremuloides; Thuja plicata
EXOPHIALA JEANSELMEI	Thuja plicata
FLAMMULINA VELUTIPES	Acer saccharum; Populus tremuloides; Salix nigricans; Sorbus americana; Ulmus thomasii

Table 1 *continued*

Fungal binominal name[2]	Substrate Trees
FOMES FOMENTARIUS	Betula alleghaniensis; B. lutea; B. papyrifera; Fagus sylvatica; Populus tremula; Populus tremuloides
FOMES ROSEUS	Picea glauca; P. mariana; Pinus contorta; Tsuga canadensis
FOMITOPSIS CAJANDERI	Picea glauca; P. mariana; P. sitchensis; Pseudotsuga menziesii
FOMITOPSIS OFFICINALIS	Picea sitchensis; Pinus ponderosa; Pseudotsuga menziesii; P. taxifolia
FOMITOPSIS PINICOLA	Abies balsamea; Betula occidentalis; Fagus americana; Larix laricina; L. sibirica; Picea excelsa; P. glauca; P. mariana; P. sitchensis; P. yezoensis; Pinus contorta; P. ponderosa; Pinus sylvestris; Populus balsamifera; P. grandidentata; P. tremuloides; Pseudotsuga menziesii; Thuja occidentalis; Tsuga canadensis; T. heterophylla
FUSARIUM OXYSPORUM	Betula papyrifera; Fagus sylvatica; Picea glauca; Pinus resinosa; Populus tremuloides Pseudotsuga menziesii
GANODERMA APPLANATUM	Acer saccharum; Betula papyrifera; Fagus sylvatica; Pinus strobus; Pseudotsuga menziesii
	Quercus rubra; Tsuga heterophylla
GANODERMA LOBATUM	Populus balsamifera
GANODERMA LUCIDUM	Quercus velutina; Tsuga canadensis
GANODERMA OREGONENSE	Abies grandis; Picea glauca; P. sitchensis; Tsuga heterophylla
GLIOCLADIUM ROSEUM	Picea abies ?; Pinus resinosa; Populus grandidentata
GLIOCLADIUM VIRIDE	Pinus banksiana
GLOEOPHYLLUM SEPIARIUM	Betula papyrifera; Populus tremuloides
GLOEOPHYLLUM TRABEUM	Abies balsamea; Acer saccharum; Picea abies; Pinus ponderosa; P. strobus; Thuja plicata
	Tsuga canadensis
GLOEOPORUS DICHROUS	Abies lasiocarpa; Acer saccharum; Betula occidentalis; Pinus contorta
GLOEOPORUS PANNOCINCTUS	Acer rubrum; Acer saccharum
HAPALOPILUS NIDULANS	Betula papyrifera; Populus trichocarpa
HERICIUM AMERICANUM	Acer saccharum; Betula alleghaniensis; B. lutea; B. papyrifera; Carya ovata; Fagus grandifolia
	Larix laricina; Plantanus occidentalis; Populus tremuloides; Tsuga canadensis; Ulmus thomasii
HERICIUM CORALLOIDES	Betula alba; Fagus grandifolia; Populus tremulus; P. trichocarpa; Quercus rubur
HETEROBASIDION ANNOSUM	Juniperus communis; Thuja plicata; Tsuga heterophylla

Table I *continued*

HIRSCHIOPORUS ABIETINUS	Abies balsamea; Picea mariana; P. rubens; Pinus banksiana; P. contorta; P. strobus; Pinus sylvestris; Pseudotsuga taxifolia; Tsuga canadensis
HIRSCHIOPORUS PARGAMENUS	Acer saccharum; Betula neoalaskana; Carpinus caroliniana; Fagus grandifolia; Populus grandidentata; P. tremuloides
HOHENBUEHELIA ANGUSTATA	Quercus alba; Ulmus americana
HYGROPHOROPSIS AURANTIACA	Pinus resinosa
HYMENOCHAETE TABACINA	Abies balsamea; A. lasiocarpa; Acer saccharum; Picea abies; Thuja plicata
HYPHOCHNICIUM VELLEREUM	Acer saccharum; Ulmus americana
HYPHODERMA HETEROCYSTIDIUM	Fagus sp.
HYPHODERMA MEDIOBURIENSIS	Acer rubrum
HYPHODERMA MUTATUM	Liriodendron tulipifera; Acer sp.
HYPHODERMA PUBERUM	Pinus strobus; Thuja occidentalis
HYPHODONTIA ARGUTA	Tilia sp.
HYPHODONTIA NESPORI	Picea orientalis; Alnus glutinosa; Fagus orientalis
HYPHODONTIA QUERCINA	Populus trichocarpa
HYPHODONTIA SUBALUTACEA	Thuja sp.; Picea orientalis; Pinus sp.
HYPOXYLON SERPENS	Pinus nigra; Fraxinus sp.; Quercus sp.
INCRUSTOPORIA SEMIPILEATUS	Betula lutea; Thuja plicata; Quercus sp.
IRPEX LACTEUS	Abies balsamea; Acer saccharum; Alnus incana; Aralia spinosa; Fagus grandifolia; Pinus banksiana; P. resinosa Populus tremuloides; Thuja plicata; Tsuga plicata; Ulmus americana
JUNGHUHNIA COLLABENS	Abies lasiocarpa; Picea glauca; P. mariana; Pinus banksiana
JUNGHUHNIA NITIDA	Populus grandidentata; P. tremuloides; Quercus dilatata; Ulmus sp.
LACCARIA BICOLOR	Picea mariana
LAETICORTICIUM ROSEOCARNEUM	Acer sp.
LAETIPORUS SULPHUREUS	Eucalyptus saligna; Picea mariana; P. sitchensis; Quercus rubra; Tsuga heterophylla
LAXITEXTUM BICOLOR	Populus tremuloides; Salix sp.
LENTINELLUS COCHLEATUS	Picea mariana
LENTINELLUS URSINUS	Acer rubrum; A. saccharum; Populus sp.
LENTINELLUS VULPINUS	Tsuga heterophylla; Acer sp.; Populus sp.; Ulmus sp.
LENTINULA EDODES	Quercus serrata; Q. mongolica; Q. acutissima
LENTINUS LEPIDEUS	Abies balsamea; Betula alleghaniensis; Picea glauca; Pinus banksiana; P. strobus
LENTINUS TIGRINUS	Fraxinus americana
LENZITES ADUSTA	Shorea robusta (log)
LENZITES BETULINA	Betula alleghaniensis; B. papyrifera; Populus grandidentata; Tilia americana
LENZITES PALISOTI	Acacia sp.
LENZITES SAPIARIA	Abies balsamea; Betula papyrifera; Pinus contorta; Populus tremuloides; Tsuga canadensis

Table I *continued*

Fungal binominal name[2]	Substrate Trees
EPTODONTIDIUM ELATIUS	Pseudotsuga taxifolia; Tsuga heterophylla
LEPTOGRAPHIUM LUNDBERGII	Pinus banksiana; P. contorta; P. strobus
LEUCOGYROPHANA ARIZONICA	Pinus sp. (log)
LEUCOGYROPHANA MOLLUSCA	Pinus strobus; Fagus sp.; Tsuga sp.
LEUCOGYROPHANA OLIVASCENS	Pinus sp.; Quercus sp.
LEUCOGYROPHANA PINASTRI	Picea glauca; Pinus australis; P. strobus; Populus sp.
LIGNINCOLA LAEVIS	Acer rubrum
LISTEROMYCES INSIGNIS	Cinnamomum japonicum (trunk)
MARIANNAEA ELEGANS	Picea sp.
MELANOMMA PULVIS-PYRIUS	Alnus rubra
MERULIOPSIS TAXICOLA	Abies balsamea; A. lasiocarpa; Juglans cinerea; Picea canadensis; Pinus banksiana
MERULIUS ARMENIACUS	Pinus sp.
MERULIUS AUREUS	Pinus strobus
MERULIUS SERPENS	Juglans cinerea; Abies sp.; Pinus sp.
MERULIUS TREMELLOSUS	Betula alleghaniensis; Populus tremuloides; Pseudotsuga menziesii; Tsuga sp.
MUCRONELLA CALVA	Acer saccharum ?
MYCOACIA UDA	Fagus sylvatica
NAEMATOLOMA SUBLATERITINUM	Acer saccharum
NECTRIA COCCINEA	Fagus grandifolia; Populus sp.
ODONTIA CILIOLATA	Populus sp.; Quercus sp.
ODONTIA FIMBRIATA	Populus sp.
ODONTIA HYDNOIDES	Acer rubrum; Populus sp.
OPHIOSTOMA PICEAE	Betula pubescens; Quercus rubra; Tsuga heterophylla
OSTEINA OBDUCTA	Picea sitchensis; Pinus sp.
OUDEMANSIELLA MUCIDA	Fagus sylvatica
PAECILOMYCES VARIOTII	Pinus contorta
PANELLUS LONGINQUUS	Tsuga heterophylla
PANELLUS PATELLARIS	Alnus sp.
PAXILLUS PANUOIDES	Picea glauca; Pinus banksiana; P. sylvestris
PENICILLIUM FUNICULOSUM	Pinus contorta; Ulmus americana
PENICILLIUM LIGNORUM	Pinus sylvestris; Fagus sylvatica
PENICILLIUM PURPUROGENUM	Prunus persica
PENICILLIUM ROQUEFORTII	Carya illinoensis; Malus sp.
PENICILLIUM THOMII	Abiés balsamea; Pinus contorta
PENIOPHORA CINEREA	Acer saccharum; Betula papyrifera; B. verrucosa; Fagus grandifolia; Pinus banksiana Pinus strobus; Prunus pennsylvanica; Tsuga heterophylla; Quercus sp.; Ulmus sp.
PENIOPHORA CREMEA	Betula alba; Quercus rubra; Pinus radiata; Pinus taeda; Populus trichocarpa
PENIOPHORA GIGANTEA	Abies balsamea; Picea glauca; Pinus banksiana; P. contorta; P. radiata; P. resinosa Pinus strobus; Pseudotsuga menziesii
PENIOPHORA INCARNATA	Ulmus americana; Betula sp.; Picea sp.
PENIOPHORA LUDOVICIANA	Alnus sp.
PENIOPHORA NUDA	Cornus stolonifera; Quercus borealis; Ulmus americana

Table I *continued*

PENIOPHORA PSEUDOPINI	Abies balsamea; Picea glauca; P. mariana; Pinus contorta; P. resinosa; P. strobus; Pinus sylvestris
PENIOPHORA SENSU-STRICTO	Pinus sp.
PENIOPHORA SEPTENTRIONALIS	Abies balsamea; Picea engelmanni; P. glauca; P. mariana; P. rubens; Pinus contorta; Pseudotsuga sp.
PHAEOCORIOLELLUS TRABEUS	Nothofagus dombeyi
PHANEROCHAETE CHRYSOSPORIUM	Abies balsamea; Fagus grandifolia; Pinus sylvestris; Populus tremuloides; Ulmus americana
PHELLINUS CONCHATUS	Fraxinus nigra; Alnus sp.
PHELLINUS FERREUS	Alnus americana; Pseudotsuga taxifolia; Thuja plicata; Tsuga heterophylla
PHELLINUS FERRUGINOSUS	Populus trichocarpa; Acer sp.; Fraxinus sp.
PHELLINUS GILVUS	Eucalyptus sideroxylon; Quercus sp.
PHELLINUS LAEVIGATUS	Betula lutea; Prunus pennsylvanica
PHELLINUS PINI	Abies lasiocarpa; Larix lyallii; L. sibirica; Picea abies; P. engelmanni; P. glauca Pinus mariana; P. banksiana; P. contorta; P. resinosa; Pseudotsuga menziesii Pseudotsuga taxifolia; Tsuga canadensis
PHIALOCEPHALA DIMORPHOSPORA	Fraxinus sp.
PHIALOCEPHALA VIRENS	Tsuga heterophylla; Picea sp.
PHIALOPHORA AMERICANA	Pinus banksiana; Populus tremuloides; Acer sp.
PHIALOPHORA FASTIGIATA	Betula lutea; Picea glauca; Pinus banksiana; P. contorta; P. glauca; P. strobus; Thuja plicata
PHIALOPHORA LIGNICOLA	Pinus sp.
PHIALOPHORA MELINII	Abies balsamea; Acer saccharum; Betula lutea; B. papyrifera; Fraxinus nigra; Picea glauca Picea mariana; P. rubens; Pinus banksiana; Populus tremuloides; Pseudotsuga menziesii Thuja plicata; Tsuga canadensis
PHIALOPHORA RICHARDSIAE	Pinus sp.
PHLEBIA LIVIDA	Abies balsamea
PHLEBIA RADIATA	Abies balsamea; Betula lutea; Pinus contorta; Populus trichocarpa; Robinia sp.
PHLEBIA ROUMEGUERII	Picea glauca
PHLEBIA RUFA	Quercus hypoleucoides; Q. robus; Acer sp.; Betula sp.
PHOLIOTA ADIPOSA	Abies grandis; Acer concolor; A. saccharum; Betula urticifolia; Populus nigra; P. tremuloides
PHOLIOTA SPECTABILIS	Acer saccharum; Populus balsamifera; P. tacamahacia; P. trichocarpa; Salix sp.
PHOLIOTA SQUARROSA	Abies lasiocarpa; Acer saccharum; Populus sp.
PHOMOPSIS MALI	Malus pumila
PHYLLOTOPSIS NIDULANS	Abies lasiocarpa; Acer rubrum; Fagus grandifolia; Ulmus americana

Table I *continued*

Fungal binominal name[2]	Substrate Trees
PIPTOPORUS PORTENTOSUS	Nothofagus pumilio
PLEUROTUS CYSTIDIOSUS	Populus deltoides; Acer rubrum; Liquidambar styraciflua; Quercus nuttallii; Ficus carica
PLEUROTUS LIGNATILIS	Acer saccharum; Fagus sp.
PLEUROTUS OSTREATUS	Acer saccharum; Fagus sylvatica; Liquidambar styraciflua; Liriodendron tulipifera Populus balsamifera; P. nigra; P. tremuloides; Salix seringeana; Tilia americana; Ulmus americana
PLEUROTUS SAPIDUS	Abies lasiocarpa (sap rot); Acer saccharum; Picea glauca; Ulmus americana
PLEUROTUS SEROTINUS	Abies lasiocarpa; Acer saccharum; Betula lutea; Pinus strobus; Populus tremuloides Pseudotsuga menziesii; Tsuga sp.
PLEUROTUS ULMARIUS	Acer negundo; A. saccharum; Ulmus americana; U. rubra
POLYPORUS BADIUS	Ulmus sp.
POLYPORUS BRUMALIS	Betula alleghaniensis; B. lutea; Picea abies; Quercus rubra; Tilia americana; Acer sp.; Alnus sp.
POLYPORUS CILIATUS	Acer saccharum; Ulmus americana
POLYPORUS COMPACTUS	Populus remuloides; Quercus alba; Q. rubra
POLYPORUS CONCHIFER	Ulmus sp.
POLYPORUS LENTUS	Fagus grandifolia; Tilia americana
POLYPORUS OSTREIFORMIS	Terminalia tomentosa
POLYPORUS VARIUS	Abies lasiocarpa; Betula papyrifera; Populus tremuloides; Thuja plicata
PORIA CARBONICA	Pseudotsuga menziesii; P. taxifolia
PORIA CRASSA	Pinus strobus
PORIA CRUSTULINA	Abies lasiocarpa; Acer saccharum; Picea glauca
PORIA FISSILIFORMIS	Populus sp.
PORIA GRISEOALBA	Populus trichocarpa
PORIA LATEMARGINATA	Acer macrophyllum; Quercus sp.
PORIA OVERHOLTSII	Pinus sp.; Quercus sp.
PORIA PLACENTA	Larix occidentalis; Picea abies; P. glauca; P. sitchensis; Pinus abies; P. banksiana Pinus roxburghii; P. strobus; P sylvestris; Populus balsamifera; Prunus serotina Pseudotsuga menziesii; P. taxifolia; Thuja plicata; Tsuga heterophylla; Quercus sp.
PORIA RHODELLA	Pseudotsuga taxifolia; Alnus sp.
PORIA SPISSA	Pinus radiata; Acer sp.; Fraxinus sp.
PORIA SUBVERMISPORA	Pinus contorta; Quercus sp.
PORIA VAILLANTII	Picea abies; P. glauca; Pinus banksiana; P. laricio; P. strobus

Table I *continued*

PORIA XANTHA	Abies lasiocarpa; Picea glauca; Pinus banksiana; P. contorta; P. resinosa; Populus trichocarpa Pseudotsuga menziesii; P. taxifolia; Tsuga heterophylla
PORONIDULUS CONCHIFER	Ulmus americana
POTEBNIAMYCES CONIFERARUM	Larix laricina
PUNCTULARIA ATROPURPURASCENS	Picea glauca; Pinus banksiana; Thuja plicata
PYCNOPORELLUS ALBOLUTEUS	Abies balsamea; Picea glauca; P. sitchensis; Tsuga heterophylla
PYCNOPORUS CINNABARINUS	Acer rubrum; Betula alleghaniensis; B. lutea; B. papyrifera; Fagus americana; F. crenata Fagus grandifolia; Prunus avium; Sorbus aucuparia; Pinus sp.
PYCNOPORUS COCCINEUS	Eucalyptus marginata; Pinus radiata; Quercus serrata
PYCNOPORUS SANGUINEUS	Fagus grandifolia; Pinus caribea; P. elliotti; P. radiata
RADULODON AMERICANUS	Populus tremuloides
RADULOMYCES CONFLUENS	Acer campestri
RHINOCLADIELLA ATROVIRENS	Pinus banksiana; P. contorta; P. strobus; Populus tremuloides; Thuja plicata; Tsuga heterophylla
RHODOTUS PALMATUS	Ulmus sp.
RIGIDOPORUS CORTICOLA	Populus tremuloides; P. trichocarpa
RIGIDOPORUS EXPALLESCENS	Fraxinus sp.; Populus sp.; Quercus sp.; Thuja sp.
RIGIDOPORUS GIGANTEUS	Fagus sp.; Robinia sp.
RIGIDOPORUS MICROMEGAS	Quercus sp.; Sequoia sp.
RIGIDOPORUS NIGRESCENS	Picea sitchensis; Quercus borealis; Tsuga canadensis
RIGIDOPORUS SANQUINOLENTUS	Acer sp.
RIGIDOPORUS VITREUS	Acer sp.; Quercus sp.
ROSELLINIA NECATRIX	Pyrus communis; P. malus
SCHIZOPHYLLUM COMMUNE	Abies balsamea; Picea glauca; Pinus contorta; P. radiata; Ulmus americana; U. thomasii
SCHIZOPORA PARADOXA	Pinus caribea; Pseudotsuga menziesii; Acer sp.; Salix sp.
SCOPULARIOPSIS BREVICAULIS	Prunus cerasus
SCYTALIDIUM LIGNICOLA	Acer saccharum; Betula papyrifera; Picea glauca; Pinus banksiana; P. ponderosa; Populus tremuloides; Pseudotsuga menziesii
SCYTINOSTROMA GALACTINUM	Abies balsamea; A. lasiocarpa; Alnus rubra; Picea glauca; Pinus resinosa; P. strobus; Pyrus malus; Tilia americana; Cornus sp.
SERPULA HIMANTIOIDES	Abies balsamea; A. lasiocarpa; Picea glauca; Pinus strobus; Thuja plicata
SERPULA INCRASSATA	Pseudotsuga menziesii; P. taxifolia; Tsuga heterophylla
SERPULA LACRYMANS	Pseudotsuga menziesii
SERPULA SILVESTER	Picea excelsa

Table 1 *continued*

Fungal binominal name[2]	Substrate Trees
SISTOTREMA BRINKMANNII	Abies balsamea; Acer saccharinum; A. saccharum; Betula papyrifera; Picea mariana; P. sitchensis Pinus banksiana; P. contorta; P. strobus; Thuja plicata; Tilia americana; Eucalyptus sp.
SISTOTREMA RADULOIDES	Picea mariana; P. rubens; Populus tremuloides; P. trichocarpa
SISTOTREMASTRUM NIVEOCREMEUM	Alnus glutinosa; Picea orientalis; Eucalyptus sp.
SKELETOCUTIS AMORPHA	Pinus resinosa
SPHAEROBOLUS STELLATUS	Pinus sp.
SPHAEROSPORELLA BRUNNEA	Pinus banksiana
STACHYBOTRYS CHARTARUM	Pinus sp.
STECCHERINUM OCHRACEUM	Acer rubrum; Ostrya virginiana; Quercus sp.
STEREUM GAUSAPATUM	Quercus garryana; Betula sp.
STEREUM HIRSUTUM	Acacia decurrens; Acer saccharum; Alnus rubra; Betula alleghaniensis; B. lutea; B. papyrifera Pinus contorta; P. radiata; Quercus sp.
STEREUM OCHRACEO-FLAVUM	Acer saccharum; Betula lutea; B. papyrifera
STEREUM OSTREA	Betula lutea; B. occidentalis; Fagus americana; Ostrya virginiana; Quercus alba
STEREUM STRIATUM	Ostrya virginiana
TALAROMYCES FLAVUS	Pseudotsuga taxifolia
TALAROMYCES STIPITATUS	Pinus virginiana
THERMOASCUS AURANTIACUS	Populus tremuloides; Ulmus americana
THIELAVIA TERRESTRIS	Populus tremuloides
TRAMETES CINGULATA	Acacia mearnsii; Eucalyptus sp.
TRAMETES SCABROSA	Cecropia peltata
TRAMETES VERSICOLOR	Fagus sylvatica; Malus domestica; Alnus rubra; Castanea sativa; Quercus serrata
TRECHISPORA RADULOIDES	Acer saccharum; Populus tremuloides
TREMATOSPHAERIA BRITZEL.	Populus sp.
TRICHODERMA AUREOVIRIDE	Acer sp.; Picea sp. (chip pile)
TRICHODERMA CITRINOVIRIDE	Betula papyrifera; Pseudotsuga menziesii; Acer sp.
TRICHODERMA GLOBOSUM	Betula lutea; B. papyrifera; Acer sp.
TRICHODERMA HAMATUM	Betula lutea; B. papyrifera; Picea mariana; Pinus strobus; P. taeda; Pseudotsuga menziesii Thuja occidentalis; T. plicata; Tsuga canadensis; Ulmus americana; Acer sp.
TRICHODERMA HARZIANUM	Betula vulgaris; Picea excelsa; Pinus banksiana; P. resinosa; P. strobus (sapwood) Pseudotsuga menziesii; Thuja occidentalis; T. plicata; Tsuga canadensis; Ulmus americana; Quercus sp.

Table 1 *continued*

TRICHODERMA KONINGII	Ostrya virginiana; Pinus taede; Tsuga canadensis; Ulmus americana; Acer sp.
TRICHODERMA MINUTISSIMA	Betula papyrifera
TRICHODERMA POLYSPORUM	Picea excelsa; P. glauca; Pseudotsuga menziesii; Thuja plicata; Ulmus americana; Quercus sp.
TRICHODERMA PSEUDOKONINGII	Betula papyrifera; Pinus ponderosa; Acer sp.
TRICHODERMA SINUOSUM	Acer sp. Ulmus sp.
TRICHODERMA VIRIDE	Betula lutea; Ostrya virginiana; Picea glauca; Pinus resinosa; Pseudotsuga menziesii Thuja occidentalis; T. plicata; Tsuga canadensis; Ulmus americana; Acer sp.; Alnus sp.; Salix sp.
TRICHODERMA XYLOPHYLUM	Acer sp.
TYROMYCES BALSAMEUS	Abies balsamea; A. lasiocarpa; Picea abies; P. glauca; P. mariana; P. sitchensis; Populus tremuloides; Thuja heterophylla; T. occidentalis; T. plicata; Tsuga heterophylla
TYROMYCES CAESIUS	Betula alleghaniensis; Thuja plicata
TYROMYCES CHIONEUS	Betula lutea; B. papyrifera; Fagus grandifolia; Acer sp.
TYROMYCES DESTRUCTOR	Abies grandis; Picea glauca; P. mariana; Pinus banksiana; P. sylvestris
TYROMYCES FUMIDICEPS	Quercus sp.
TYROMYCES MOLLIS	Abies balsamea; Pseudotsuga menziesii; Tsuga sp.
TYROMYCES PALUSTRIS	Prunus persica
TYROMYCES SEMISUPINUS	Pinus canadensis; Acer sp.
TYROMYCES SERICEOMOLLIS	Abies balsamea; Larix sibirica; Picea glauca; Pinus seratina; P. strobus; P. sylvestris Thuja plicata
TYROMYCES SPRAGUEI	Quercus sp.
TYROMYCES STIPTICUS	Abies balsamea; Picea excelsa; Pinus sylvestris; Quercus sp.
TYROMYCES TEPHROLEUCUS	Acer sp.
TYROMYCES UNDOSUS	Picea morinda; Pinus contorta
VARARIA EFFUSCATA	Betula lutea; Quercus prunus; Ulmus americana; Acer sp.
VARARIA INVESTIENS	Acer sp.;, Quercus sp.
VOLVARIELLA BOMBYCINA	Ulmus sp. (trunk)
XENASMA TULASNELLOIDEUM	Picea glauca; Salix sp.
XYLARIA POLYMORPHA	Pinus strobus; Salix alba
XYLOBOLUS FRUSTULATUS	Quercus alba
ZALERION MARITIMUM	Pinus ponderosa; P. sylvestris

[1] Fungal collection accession numbers of organisms cited can be found in files deposited in the Instutute's library.

[2] Synonymous names of fungi can be found in the appendix

* For clarity, binominal names of fungi are printed in capitals and names of trees in upper & lower cases

A more general view of the diversity of fungi on wood may be had by assessing the number of fungal genera found on wood products and on trees without restriction of tree or fungal classification beyond the genus level. Two hundred and twenty three fungal genera were found that had been isolated from trees (possibly fallen) and from wood products but, at the species level only 119 were reported in more than 5 isolations and only 33 in 20 or more. Ten genera: *Poria* (140), *Peniophora* (125), *Polyporus* (120), *Tyromyces* (86), *Fomes* (85), *Trichoderma* (72), *Phellinus* (71), *Stereum* (54), *Coriolus* (53) and *Inonotus* (52) were represented by more than 50 isolations. These numbers are in some ways dubious because of taxonomic ambiguity, for example species of *Inonotus, Omnia* and *Phaeolus* are often classified as *Polyporus* and in addition there is often confusion with regard to anamorph/telemorph status e.g. *Ceratocystis/Ophiostoma, Chrysosporium/Sporotrichum/Phanerochaete.* In Table I the names of fungi used by the collections are given but for ease of reference a summary of synonyms may be found in the appendix to this review. This appendix should also be consulted when referring to names in Tables III, IV and V.

Geographical distribution of substrates of wood fungi

The number of selected fungi from both wood products and from trees in Canada was 501, followed by the United States (88) and Eurasia (65) and these comprised 95% of those on the file. Isolations were obtained from 29 countries. In Canada there were fungal specimens from all provinces though only one each from Prince Edward Island and Newfoundland. Almost half (43%) were isolated in Ontario. For the isolations from the United States only 42% reported the state where the culture originated; of those specified 43% came from Northern States. Ninety six percent of the isolates from Europe were obtained from countries north of latitude 45°. Details are given in Table II.

Table II Geographical distribution of Fungal Isolates, maintained in Six Culture Collections from Trees and Wood products

Country/State/Province	Number of different fungi isolated from both wood products & trees	isolated only from trees[1]
Africa	1	
Argentina	2	1
Australia	1	4
Austria	1	2
Canada	1	2
Alberta	51	120
British Columbia	99	176
Labrador, Newfoundland	1	14
Manitoba	8	16
New Brunswick	28	55
Nova Scotia	9	23
Ontario	213	265
Prince Edward Island	1	2
Québec	81	134
Saskatchewan	9	17
Brazil	1	
Czechoslovakia	2	
Denmark	3	1
Finland	2	3

Table II *Continued*

Country/State/Province	Number of different fungi isolated from both wood products & trees	Number of different fungi isolated only from trees[1]
France	4	5
Georgia (ex USSR)		3
Germany	4	3
Greece	1	
Hungary	2	
India	6	7
Ireland	1	
Japan	8	2
Netherlands	2	3
Norway	5	8
Poland	1	1
Puerto Rico	3	1
Republic of South Africa	1	2
Russia		
Kurgan	1	
Leningrad	2	2
Moscow	1	1
Siberia	3	
Spain	1	
Sweden	14	9
Switzerland	2	1
Turkey	7	
Ukraine		7
United Kingdom	8	13
United States	51	79
Arkansas	1	
California	4	2
Colorado	1	
Georgia USA	2	1
Indiana	2	1
Iowa	1	
Louisiana	2	1
Maine	1	1
Maryland	4	
Minnesota	2	
Mississippi	1	
New York	2	6
North Carolina	4	
Oregan	4	5
Rhode Island	1	
Virginia	2	
West Virginia		1
Washington	2	1
Wisconsin	1	3

[1] That is fungi not included in column 2.

Data is also given in Table II of fungal isolations from living trees in the various countries , their geographical distribution is similar, but rather more isolations have been reported e.g. 824 from Canada and 101 from the U.S.A.; 22 countries are represented in Table II in this category.

Some aspects of the physiology of fungi isolated from wood

The degradation of wood by enzymes produced by fungi

Sixty nine genera or about 44% of the fungal genera given in Table I have been found to produce enzymes that degrade wood (Table III). Of these 69 genera 20 have not been recorded as isolates from wood products e.g. lumber, but have been commonly found on trees.

Degradation of polysaccharides A great deal of work has been done on the degradation of the structural polysaccharides found in wood by the fungi given in Table I and the subject has been reviewed (Élisashvilli 1993). An attempt to summarize and expand the information in Élisashvilli's review with particular reference to wood is made in columns 2, 3 and 4 of Table III. Of the 69 genera given in Table III, 57 are known to produce cellulases of which 15 have been characterized as ß-1,3-glucanases and many of these also produce xylanases. One genus (*Bjerkandera*=?*Polyporus*) has been reported to produce a mannanase and a ß-1,3-glucanase (Eriksson & Goodell, 1974). Pectinase activity is also common in these fungi and three examples are given (*Armillaria, Bjerkandera* & *Heterobasidion*) in Table III.

Table III Recorded production of polysaccharide and lignin degrading enzymes by fungi found on wood and its parent trees; numbers indicate reported presence and references[1]

Fungal genera	Polysaccharide degradation			Lignin degrading enzymes		
	General	β-1,4-glucan	Xylan	Ester	Laccase	Peroxidase
Acremonium[2]	1, 2					
Alternaria[2]	3					
Amanita[2]	4, 5					
Armillaria[2]	6[3]			7		7
Armillariella[2]	8					
Aspergillus	9, 10 11, 12		13			
Bjerkandera	14, 15[3]		15		15	
Botrytis[2]	16	17				
Calocera	18				18	
Cerinomyces	18				18	
Cerrena	19		19		100	
Chaetomium[2]	20					
Cladosporium	21					
Collybia						99[5]
Coniophora[2]	22	22				
Coriolus	14, 23	24			101	
Cyathus	25				25, 26	
Dacromyces	18				18	
Daedalea	14, 19		19			
Daedalopsis (≈ *Junghuhnia*)						
Flammulina	19		19			

Table III *Continued*

Fungal genera	Polysaccharide degradation			Lignin degrading enzymes		
	General	β-1,4-glucan	Xylan	Ester	Laccase	Peroxidase
Fomes	14, 27	28			29	27
Fomitopsis	19		19			
Fusarium	30, 31		32, 33			
Ganoderma	34, 35				37	35
Geotrichum[2]	38	39				
Gliocladium	40	41				
Gloeophyllum					42	
Gloeoporus					43	
Helminthosporium[2]	44					
Heterobasidion	4[4], 45[3]				29	
Inonotus[2]	27					27
Irpex	46					
Junghuhnia					47	47
Laetiporus		48				
Lentinus	49	50			43	51
Lenzites	14					
Leptographium				52		
Merulius (Phlebia)					43	53
Nectria	54					
Ophiostoma			95			55
Panus	19		19		29, 56	56
Paxillus	4[4]					99[5]
Penicillium		57				
Perenniporia	14					
Pestalotiopsis[2]	58					
Phanerochaete						98
Phellinus	14, 59				29, 59	59
Phlebia	19		19	60	61, 63	60, 62[5]
Phoma[2]	64					
Phialophora	65					
Piptoporus	50, 19		19			
Pleurotus	50, 66	67	19	68	29, 68	
Polyporus	14				43, 69	
Postia (Poria)	70					
Pycnoporus					43, 101	
Rigidoporus[2]				71		
Schizophyllum	72	73	74			
Sporotrichum[2] ≈*Phanerochaete*		75, 92		93		94[5]
Stereum					29	
Suillus[2]	4, 76[4]			77		
Scytalidium					97	
Thermoascus		78				
Thielavia	79					
Trametes	14	24	80			81, 82[5]
Tremella[2]	96			37		
Trichothecium[2]	83					

Table III *Continued*

Fungal genera	Polysaccharide degradation			Lignin degrading enzymes		
	General	β-1,4-glucan	Xylan	Ester	Laccase	Peroxidase
Trichoderma	84, 85 12, 86		33			
Verticillium[2]	87, 88					
Xylaria[2]		89	90, 91			

[1] References

1 Leuchtmann & Clay, 1990
2 Mal & Sharma, 1987
3 Kim & Lee, 1976
4 Maijala et al., 1991
5 Natarajan & Kannan, 1982
6 Wahlstrom et al., 1991
7 Morrison et al., 1985
8 Chrapkowska, 1980
9 Hurst et al., 1977
10 Oh et al., 1985
11 Okada, 1985
12 Tan et al., 1987
13 Rho et al., 1990
14 Rodeia, 1983
15 Eriksson & Goodell, 1974
16 Verhoeff et al., 1983
17 Sasaki & Nagayama, 1996
18 Seifert 1983
19 Élisahvilli, 1993
20 Suhgal & Agarwahl, 1973
21 Lynch et al., 1981
22 Schmidhalter & Canevascini, 1992
23 Danilyak & Katson 1987
24 Mel'nychuk et al., 1982
25 Abbot & Wicklow, 1984
26 Wicklow et al., 1984
27 Rodeia et al., 1990b
28 Eghbaltalab et al., 1976
29 Blaich & Esser, 1975
30 Forbes & Dickinson, 1977
31 Ortega, 1990
32 Christakopoulos et al., 1996
33 Poutanen et al., 1987
34 Ko & Kim, 1986
35 Rodeia et al., 1990a
37 Hsen et al., 1989
38 Rabinovich et al., 1977
39 Rumyantseva & Rodionova, 1982
40 Mal & Sharma, 1985
41 Todorovic et al., 1993
42 Haider & Trajanowski, 1980
43 Reid & Siefert, 1982
44 Ghewande & Despande, 1976
45 Karlsson & Stenlid, 1991
46 Kawai et al., 1979
47 Vares et al., 1992
48 Danylyak, 1980a
49 Ginterova et al., 1981
50 Ginterova et al., 1980
51 Leathan, 1986
52 Zambino & Harrington, 1989
53 Blanchette & Reid, 1986
54 Moubasher & Mazen, 1991
55 Jeng et al., 1988
56 Maltseva et al., 1986
57 Wood et al., 1980
58 Raman, 1988
59 Fyudaraw & Marshchakina, 1981
60 Niku-Paavola et al., 1988
61 Karhunen et al., 1990a
62 Karhunen et al., 1990b
63 Gayazov & Rodakiewicz-Nowak, 1996
64 Uspenskaya & Reshetnikova, 1981
65 Garrett, 1974
66 Hong et al., 1984
67 Danylyak, 1980b
68 Zervakis & Labarere, 1992
69 Vänngård, 1972
70 Wolter et al., 1980
71 Fofana et al., 1992
72 Clarke & Yaguchi, 1986
73 Willick & Seligy, 1985
74 Paice et al., 1978
75 Canevascini et al., 1983
76 Dahn et al., 1987
77 Keller, 1992
78 Tong et al., 1980
79 Sandhu et al., 1985
80 Roy et al., 1996
81 Johnasson & Nyman, 1993
82 Jonhasson et al., 1993
83 Hasija & Agarwal, 1977
84 Brewer et al., 1987
85 Dwivedi et al., 1988
86 Wojtczak et al., 1987
87 Bahkali, 1989
88 Carder, 1989
89 Wei et al., 1996
90 Brunner & Petrini, 1992
91 Rodrigues et al., 1993
92 Lymar et al., 1995
93 Kirk et al., 1978
94 Sundramoorthy et al., 1994
95 Binz & Canevascini, 1996
96 Hanson & Wells, 1991
97 Pedersen et al., 1998
98 Ding & Gai, 1997
99 Gramss, 1997
100 Luterek et al., 1997
101 Aso & Oda, 1996

[2] Only isolated from trees
[3] Also pectinolysis
[4] Also proteolytic
[5] Also Mn^{+2} peroxidase

It is clear that these fungi, of which 30-40 are Basidiomycetes, produce very complex mixtures of polysaccharide degrading enzymes, but few have been purified and characterized. In some cases e.g. *Agaricus bisporus* (Manning & Wood, 1983) cellulase is known to be induced by cellulose and the heterogeneous nature of the cellulases of *Schizophyllum commune* is thought to be a consequence of variable transcription and subsequent glycosylation (Willick & Seligy, 1985). The cellulases of *Trichoderma* species have probably been studied to a greater extent than all the other genera in Table III (for reviews see, Koivula et al., 1998; Biely & Tenkanen, 1998). *Trichoderma* spp. are, of course, extremely cosmopolitan and have been isolated from soils in many different locations. However, unlike 9 or 10 other cosmopolitan genera in Table III (e.g. *Penicillium, Alternaria, Fusarium* etc.), the *Trichoderma* have been reported endogenously in thin wood sections (Dinulescu, 1979) and are prolific producers of cellulases (Brewer *et al.*, 1987, Madan & Mohindra, 1981, Wojtczak *et al.*, 1987). The rates of formation of ß-glucosidases and xylanases by *Cerrena unicolor* on defined media were found to be greatest after 10 days growth (Élisashvilli 1993).

Lignin degrading enzymes of fungi isolated from wood

Less is known of the degradation of lignin by fungi than their degradation of structural polysaccharides, but many Basidiomycetes degrade both (Table III). This has been construed to indicate a delicate equilibrium for the decomposition of lignin exposes cellulose fibers but also results in the production of phenols that inhibit the enzymes (Ander & Eriksson, 1976). Support for this equilibrium has been obtained (Preston *et al.*, 1990) by solid state nuclear magnetic resonance studies of the degradation of the wood of *Pseudotsuga menziesii, Tsuga heterophylla and Thuja plicata.*

A review of enzymic lignin degradation has been published (Kirk & Farrell, 1987). There are many reasons for the neglect of this subject possibly because lignin is traditionally regarded as an inconvenient byproduct of the production of paper. As a result, efforts have been concentrated on its removal from wood, mostly by treatment with chlorine or hydrogen peroxide but also particularly in recent years by biological methods. Thus much of the work reported in this section has been stimulated from this point of view.

Of the 69 genera given in Table III, 35 have been reported to degrade lignin. These reports vary from the loss in weight of wood not associated with polysaccharide degradation (Reid & Seifert, 1982) and reports of "laccase" as a taxonomic tool (e.g. Molitoris & Prillinger 1986; Zervakis & Labarere, 1992), to preparation of proteins assumed to degrade lignin because of their catalysis of the decomposition of lignin-like substrates (Hsen, et al., 1989; Johansson & Nyman, 1993; Karhunen, et al., 1990) e.g. the conversion of veratryl alcohol to veratraldehyde or merely "tyrosinase" (Moore *et al.*, 1987). An attempt has been made in Table III to indicate the nature of some of the enzymes reported. Lignin is known (Kirk & Farrell, 1987) to contain many ester linkages and thus reports of its general degradation without further elaboration of the process has been classified (probably incorrectly) under this heading in the fifth column of Table III. In the sixth column of this Table we have accepted author's designations of "laccase" though in most cases this has been used as a general handle and has not been restricted to the copper containing proteins (Vänngård 1972; Vares *et al.*, 1992). Finally, reported isolations of lignin peroxidases are given in the seventh column of Table III together with an indication of the presence of manganese peroxidases where this has been reported. Some of these manganese peroxidases require hydrogen peroxide and others are inhibited by phenylalanine (Akmanatsa & Shimada, 1996)

Colored or potentially colored metabolites of the fungi of wood

A walk through the Northern hemisphere woods in the fall reveals to the naturalist many colored fungi growing on trees, fallen logs and on the forest floor where, to the knowledgeable, their substrate is the woody roots of trees. Some of these plants have been used for the extraction of dyestuffs for wool and silk for millenniums (Caneparius, 1619), on the other hand the deterioration and disfigurement of wood by fungi has also been common knowledge. Some aspects of the latter have been reviewed and attention is drawn to the report of a symposium on sapstain (Wingfield et al., 1993). Here we are concerned with the ecology of these fungal metabolic products and details of their physiology with respect to their woody substrates. Our interest is not only with their role in the disfigurement of wood but also, speculatively, with their potential part in its durability and its beauty in the hands of a cabinet maker.

An attempt has been made in Table IV to summarize the data on which this section is based. Column 1 of Table IV is a list of 111 fungal genera that have been reported to produce metabolites that are colored or may be converted into colored entities by simple chemical transformations. These genera are assembled from 1394 culture specimens representing 605 species in the collections DAOM, FTK, VKM, ATCC, NOF and FSC. The script used in the first column of Table IV indicates the woody substrate on which the culture specimens were found as follows: italics indicate occurrence on both trees and wood products; lower case indicates presence only on trees and capitals isolations only from wood products. In the second column of Table IV are the number of cultures of different species (given in parenthesis) of the genera in column 1 found in the collections.

Column 3 of Table IV is an attempt to indicate the number of metabolites reported to have growth inhibitory properties, for each genus in column 1. The total number (2561) is approximate because it does not include congeners nor, reports we have missed. In the fourth column are given the number of recorded metabolites that are colored or potentially colored (see below) produced by species of the genus indicated. In addition 27 genera are included in Table IV that have been reported to produce colored metabolites, where the producing isolate has only been identified to the genus level. They are included because we believe there is a possibility that the producing fungus is identical to one isolated from wood. Only 3 genera (*Bjerkandera, Cylindrocarpon* and *Scopulariopsis*) comprising 6 species and producing 3 metabolites were isolated from wood and identified to the genus level.

The fifth column of Table IV is an attempt to summarize the complex chemistry of this group of metabolites, by indicating in roman numerals their structures (given in the text) or molecular formulae where these have been properly established in a chemical sense; the supporting data is to be found in the references given in column 6.

As mentioned above, the dyestuffs produced by some of the fungi in Table IV have been known and used for a long time but details of their chemistry became apparent only in the late nineteenth century when Stahlschmidt (1877) published his work on polyporic acid (Fig 1, I, R=R′=C_6H_5), and Thörner (1878) on atromentin (I, R=R′=4-HOC_6H_4) their structures being confirmed by synthesis many years later

(Kögl, 1926; Brewer et al., 1977). These 2,5-dihydroxybenzoquinones are often isolated as such from the plant tissues (Brewer *et al.*, 1968) but it seems likely that the

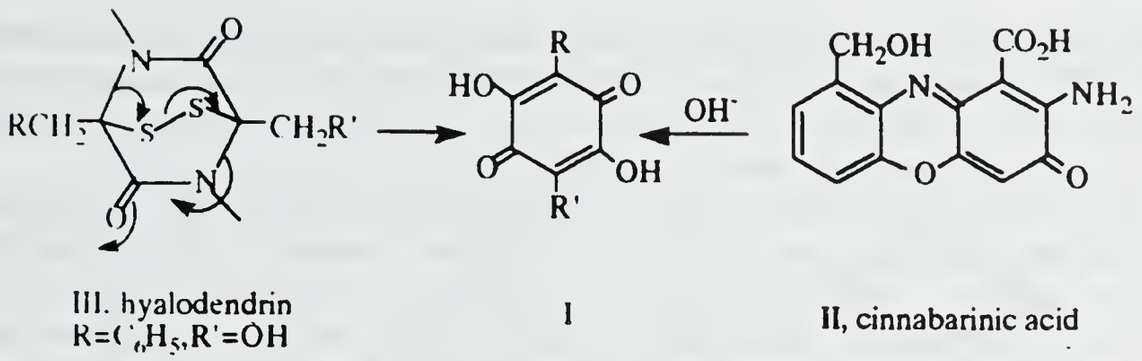


Fig 1 Routes of formation of 2,5-dihydroxy-1,4-benzoquinones.

colors exhibited by the fungi are due to adsorption of their reduced (1,2,4,5-tetrahydroxy) forms by e.g. proteins close to the surface of the plant and subsequent aerial oxidation in the classical vat-dying process. Important evidence that this is the case has been reported by Steglich and his co-workers (Holzapfel *et al.*, 1989) who have shown that little atromentin (Fig 1, I, R=R'=4-C_6H_4OH) occurs as such in *Paxillus atromentosus*, but is present therein as its reduced form possibly stabilized by esterification with 4,5-epoxy-Δ^2-hexenoic acid. These reduced metabolites have similar biological activity to their quinonoid congeners (Brewer *et al.*, 1984). Similarly the "blueing" of fungal tissue when damaged and thus exposed to air may be regarded as evidence for the existence of leuco forms (Beaumont *et al.*, 1968). Another mode of formation of these quinones from phenoxazines e.g. II (Fig 1) has been reported by Gripenberg (1958). These dihydroxybenzoquinones are often accompanied by other pigments closely related to them by oxidation, (Brewer *et al.*, 1968; Taylor & Walter, 1978) and/or dehydration or trivial elaborations (e.g. VII). Examples of oxidative change are atromentic acid (IV, R=H; Singh & Anchel, 1971; Bresinsky et al., 1974) and its hydroxylated congener variegatic acid (Fig 2, IV, R=OH; Beaumont *et al.*, 1968; Basinsky & Bachmann, 1971).

The xylerithrin pigments (V, Gripenberg, 1965) and such metabolites of *Paxillus panuoides* as flavomentine (Fig 1, I, Besl *et al.*, 1989) are elaborations of this molecular

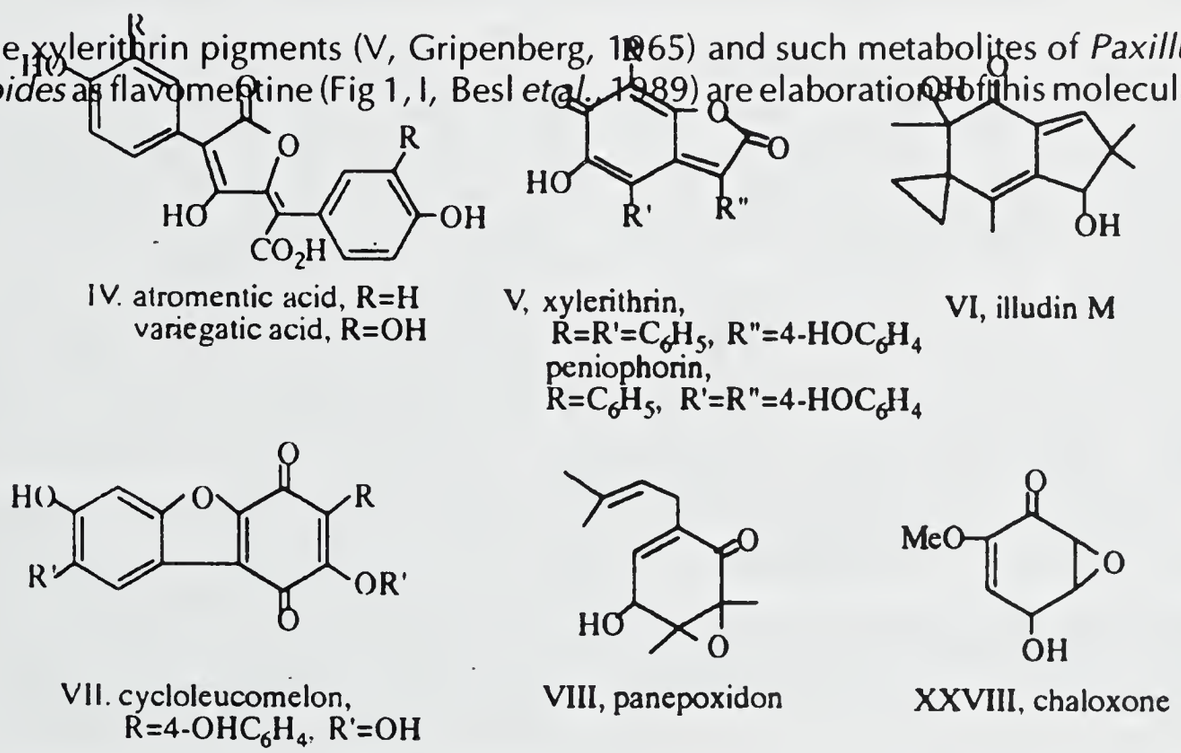
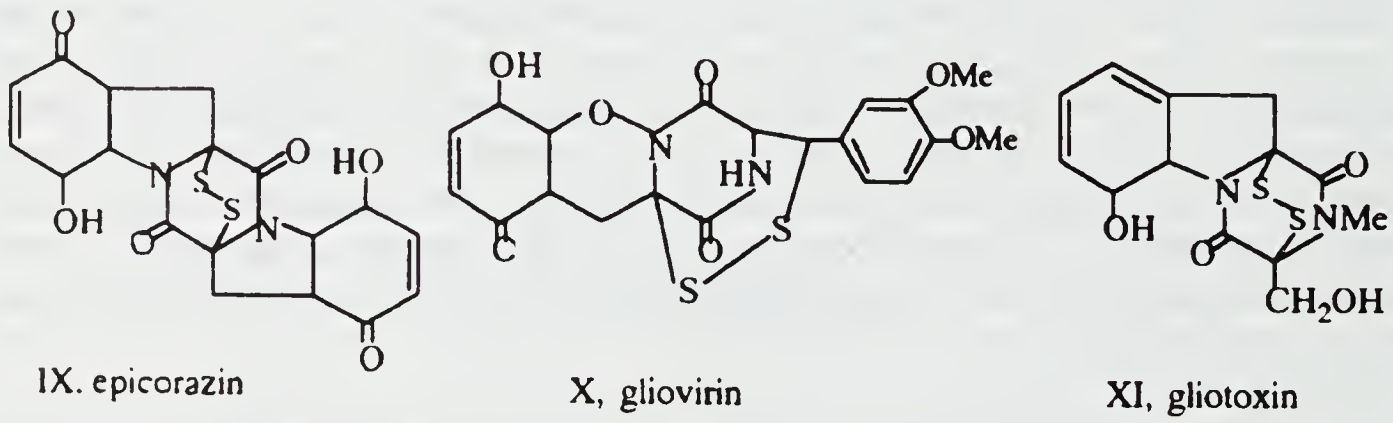


Fig 2 Metabolites structurally related to 2,5-dihydroxy-1,4-benzoquinones.

theme; and, possibly illudin M (VI, Morisaki *et al.*, 1985) and panepoxidon (VIII, Kis *et al.*, 1970). There exist examples of 2,3-dihydroxybenzoquinones - auantiogliocladin (Vischer, 1963) thought to be 2,3-dimethoxy-5,6-dimethylbenzoquinone produced by a *Gliocladium* sp. and spiromentins from *Paxillus* spp. (Best *et al.*, 1989).

Among biosynthetic studies of these compounds the most familiar to us is that of cochliodinol (I, R=R'=5-prenylindolyl-3). It has been shown (Taylor & Walter 1978) to be derived from two mols of tryptophan and all the carbon atoms of the amino acid side chain are incorporated into the benzoquinone ring. Since the oxygenated carbon atoms of this ring are equally labelled it follows that the dimerization of an intermediate occurs but the nature of the monomer and the reaction mechanism remain unknown. Speculatively such a monomer could be generated from a related epidithiodioxopiperazine e.g. hyalodendrin (III, Strunz *et al.*, 1973) by a mechanism such as that shown (Fig 1). A similar dimerization occurs in the related sporidesmin series giving rise to an indigo derivative (Hodges *et al.*, 1963). Indigo is a known metabolite of the wood rotting fungus *Schizophyllum commune* (Miles *et al.*, 1956). Two other potential quinones (IX & X) containing disulfide bridges and probably derived from amino acids (Fig 3) have been described (Baute *et al.*, 1978; Howell & Stipanovic, 1983), the former is produced by *Epicoccum nigram* which also produces the hydroquinone flavipin (Fig 8, XXV, Raistrick & Rudman, 1956).



IX. epicorazin X, gliovirin XI, gliotoxin

Fig 3 Epidithiodioxopiperazine metabolites of fungi isolated from wood.

A number of colorless metabolites, not included in Table IV are, nevertheless relevant to this discussion because they are related to shikimic acid, itself the progenitor of the amino acid precursors of the vat dyestuffs discussed in the preceding paragraphs. These compounds have been isolated from *Chalaria* spp. whose substrates were both wood products and the woody limbs of trees. Fex and his coworkers (Fex, 1981; Fex & Wickberg, 1981; Fex *et al.*, 1981) have isolated 3,4-anhydroshikimic acid and chaloxone (Fig 2, XXVIII), both are clearly related to the dihydroxybenzoquinones. Ceratenolone (Fig 8, XXIX, Ayer *et al.*, 1987) not surprisingly produces a blue color on reaction with ferric ion and is thought to be involved in sapstain of wood. The role of such chelators may, however be important in fungal degradation of wood and a review of this subject has recently been published (Goodell et al., 1997).

Another group of pigmented metabolites, that may be biosynthesized by polyketide intermediates are anthraquinones (Fig 4) such as emodin (1,3,8-trihydroxy-6-methylanthraquinone, Ayer *et al.*, 1983) and more elaborate derivatives e.g. averufin (XII, Pusey & Roberts, 1963). Hydroxylated naphthoquinone metabolites of these fungi are also common e.g. javanicin (XIII, Arnstein & Cook 1947), many congeners e.g. herbarin (Nagarajan et al., 1971) and hydrogenated derivatives such as scytalone (Fig 8, XXVII, Aldridge *et al.*, 1974). Naphthoquinone fungal metabolites have been reviewed (Medentsev & Akimenko 1998).

There are also complex assemblies of quinonoid metabolites such as the calphostins (Fig 4, XVI, Iida *et al.*, 1989) and the related altertoxins (XVII, Stinson *et al.*, 1982; Hradil

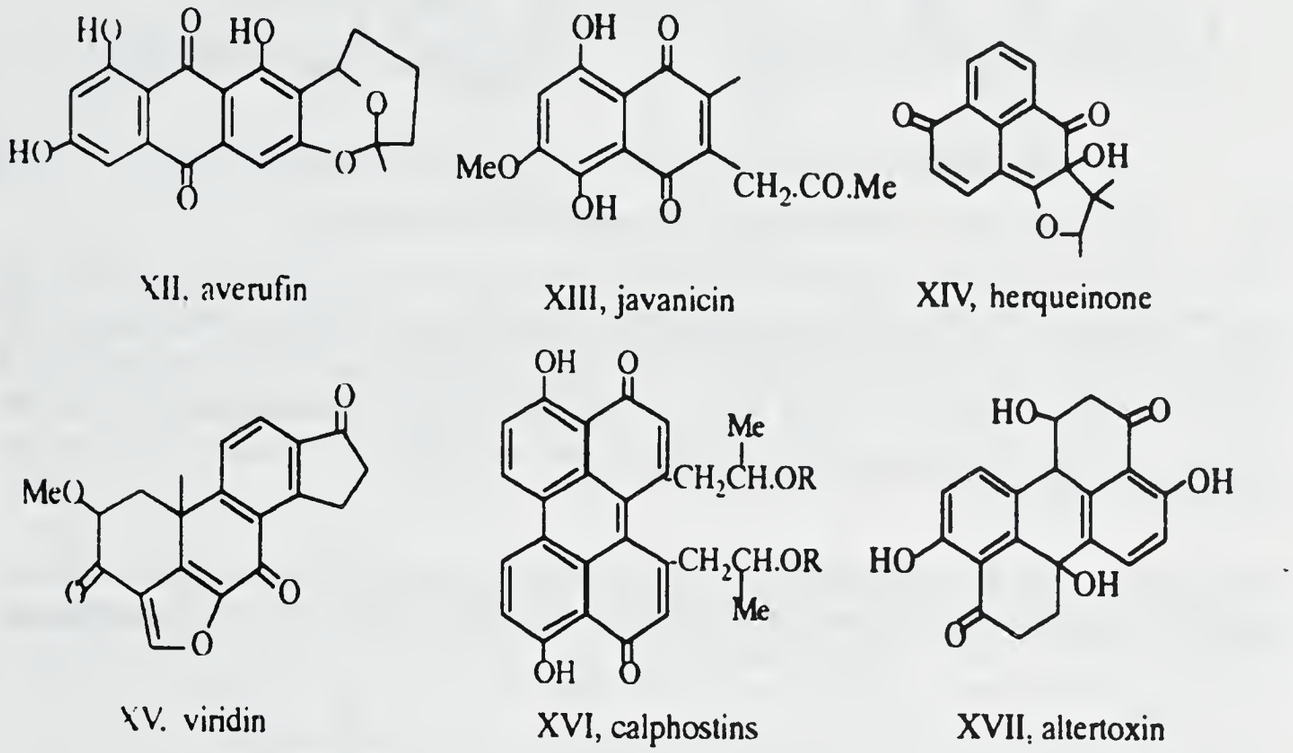


Fig 4 Quinonoid metabolites of wood fungi.

et al., 1989), herqueinone (XIV, Quick *et al.*, 1980) and viridin (XV, Grove *et al.*, 1965, 1966)

Apart from viridin many of these are compounds are biosynthesized by a polyketide pathway (Aldridge *et al.*, 1974) and hence are related to fatty acids, but other relatives of these acids are possibly of greater interest in connection with the pigmentation of wood and its properties. These relatives are acetylenic in nature and the simplest of these is hexa-1,3,5-tryne (Glen *et al.*, 1966). This compound is, however, only one of a large number of relatives that have been extensively studied by Jones and his colleagues (e.g. Gardner *et al.*, 1960; Farrell *et al.*, 1987) who have shown them to be metabolites of many of the genera in Table I e.g. *Merulius, Pleurotus, Polyporus, Tricholoma* and *Leptoporus.* Many of these compounds are derivatives of nona-2-en-4,6,8-triyne indicated as $R(C{\equiv}C)_3H$ schematically in Table IV; all are unstable and in most cases carbon is one of their decomposition products. As far as we know the allotropic form of this carbon has not been investigated, but in view of the known strength of some of the carbon tubular allotrophs (Goroff. 1996; Terrones *et al.*, 1995) it is intriguing to speculate that some of the tensile strength of wood may be due in part to such embedded entities. Although the details of the nature of the products of the reactions of these polyacetylenes remain obscure there are a group of metabolites of *Stereum* spp. that might be derived from them e.g. frustulosin (Fig 6, XVIII, R=CHO), siccayne (XVIII, R=H) and nitidon (LXXXVII).

There are a number of colorless coumarins and related compounds that have been included in Table IV because of their ability to form colored oxonium salts by the well known process e.g. Fig 5 (Bayer & Kneifel, 1972).

Examples among the 2H-pyrones are altenuisol (Fig 6, XIX) and its congeners, produced by *Alternaria* spp. (Bottini *et al.*, 1981; Nakajima *et al.*, 1976; Pero *et al.*,

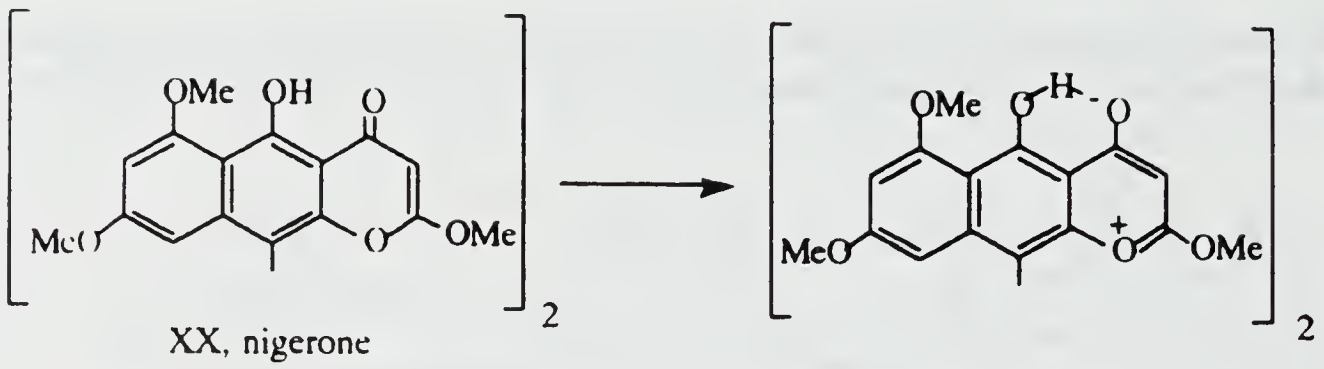


Fig 5 Formation of oxonium salts from substituted γ-pyrones.

1973; Visconti *et al.*, 1989) and among the 4-H pyrones may be mentioned the nigerones (Fig 5, Gorst-Allman & Steyn, 1980), eugenitin (XX; X=Me, Y=Me, Coombie *et al.*, 1972), lateropyrone (XXIa, Bushnell *et al.*, 1984), chloromonocillin and its analogues (XXII, Sassa *et al.*, 1983, 1985) and mycoxanthone (LX, Assanti *et al.*, 1979; Ayer *et al.*, 1989).

One further group of metabolites are of interest. These are isocyanides and include the yellow-orange xanthocillins (LXXXVI, Itoh *et al.* 1990) and the *cyclo*pentylisocyanides

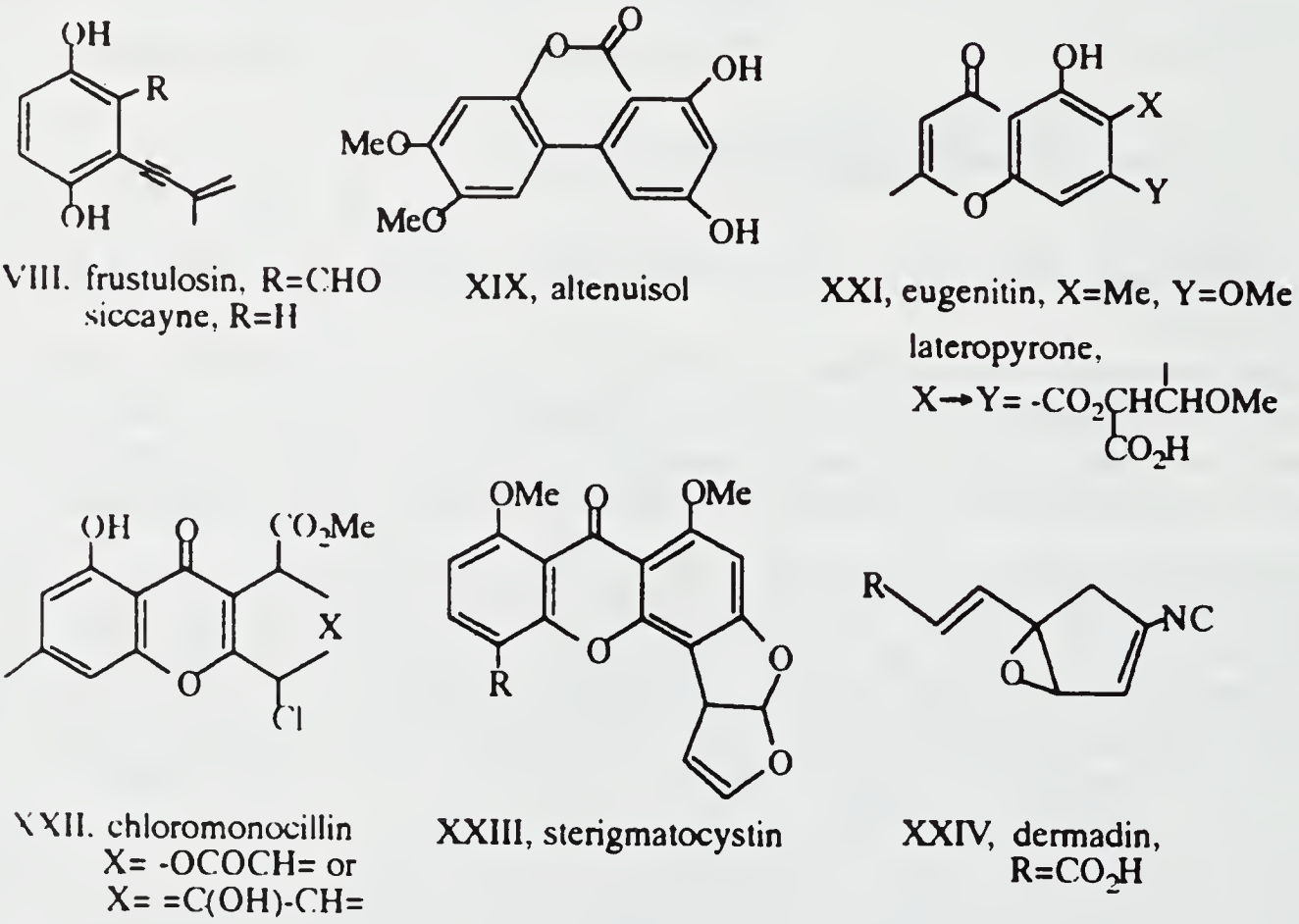


Fig 6 Miscellaneous colored or potentially colored metabolites of fungi commonly isolated from wood.

such as dermadin (XXIV, R=CO_2H, Brewer *et al.*, 1982). About 14 of these metabolites have now been characterized (Boyd *et al.*, 1991; Lee et al., 1997) but a number of others are produced by the mould. All are colorless but all polymerize in the presence of traces of nickelous ion to brown or black polymers by the sequence (Fig 7, Nolte *et al.*, 1973):

Since the demonstration of the presence of *Trichoderma* spp. in thin sections of wood (Dinulescu, 1979) it is possible that the pigmentation of wood by this type of

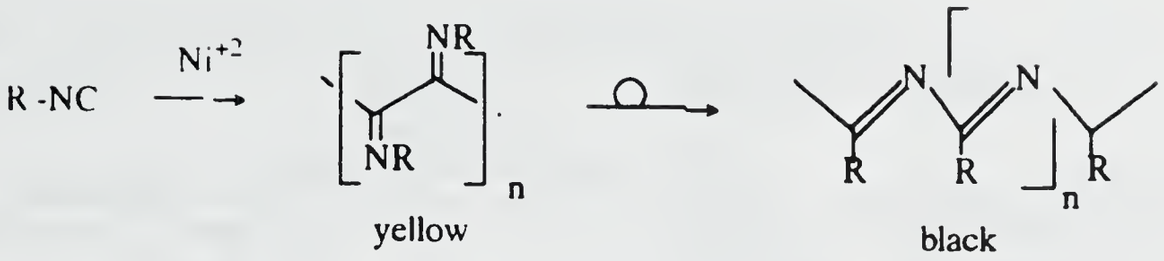
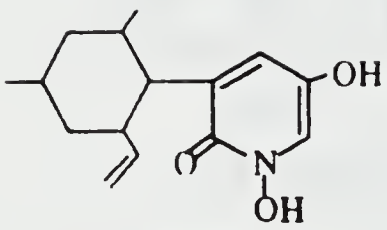


Fig 7 Polymerization of isocyanides in the presence of nickelous ion.

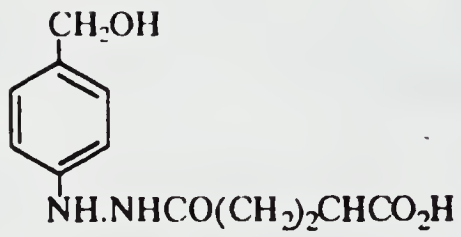
polymerization occurs. Thus wood may be disfigured by this process, but alternatively, the beautiful brown or even purple coloration of hardwoods may arise in this manner. Acidic isocyanides (e.g. XXIV, R=CO_2H, Fig 6) may also polymerize by the Ugi four component condensation (Ugi, 1982) i.e.

$$(C{=}N\text{-}X\text{-}CO_2^-NH_4^+)_2 + RCOR' \rightarrow C{=}N\text{-}X\text{-}CO\{NH.C(RR')CO\}_nNH\text{-}X\text{-}CO_2NH_4 \rightarrow$$

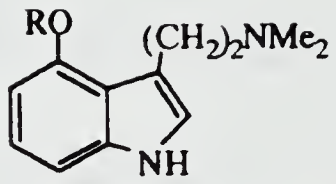
Polypeptides of this type are common metabolites of *Trichoderma* spp. and many of the genera given in Table IV (Shaw & Taylor 1986). They require an insoluble polysaccharide in the media used for their production (Brewer *et al.*, 1987). Hence this type of polymerization may occur *in situ* in wood and because of the growth inhibiting properties of these peptides (Jen *et al.*, 1987) might be a mechanism to ensure resistance to microbial pathogens. Similar mechanisms have been suggested (Schulz *et al.*, 1995) for the action of antifungal metabolites of *Pezicula* spp.



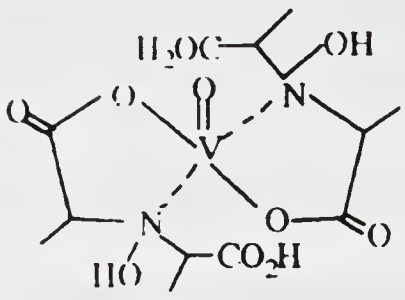
XXXI. pyridoxatin



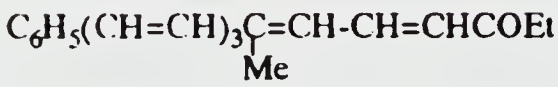
XXXII, agaritine



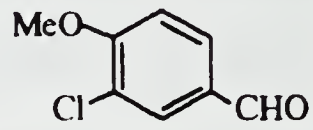
XXXIII,
psilocin, R=H
psilocybin, R=PO_3H_2



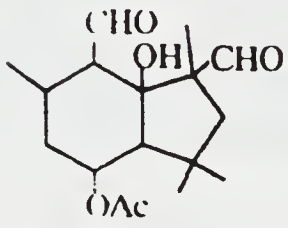
XXXIV, amavadin



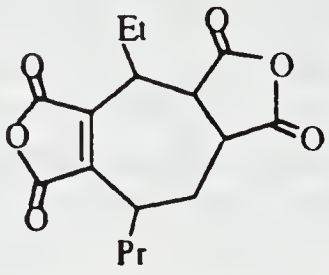
XXXV, asperyellone



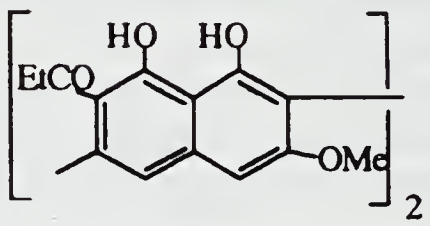
XXXVI



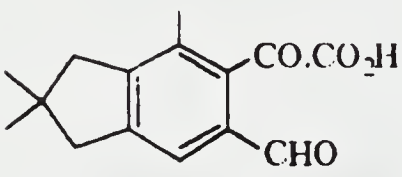
XXXVII. botrydial



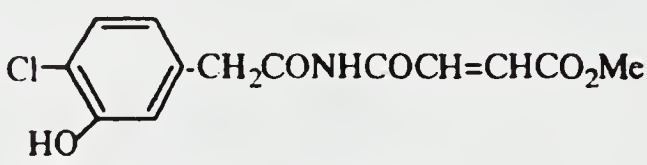
XXXVIII, byssochlaminic acid



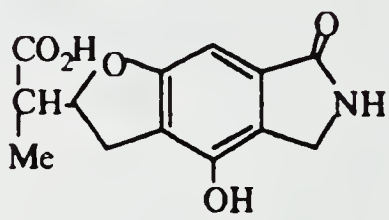
XXXIX



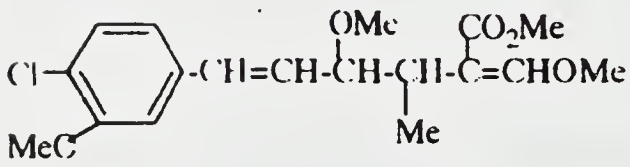
XL. clavicoronic acid



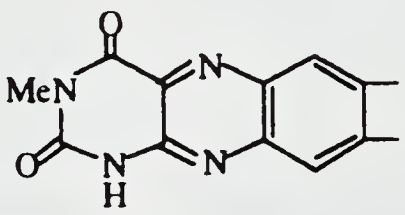
XLI, coniothyriomycin



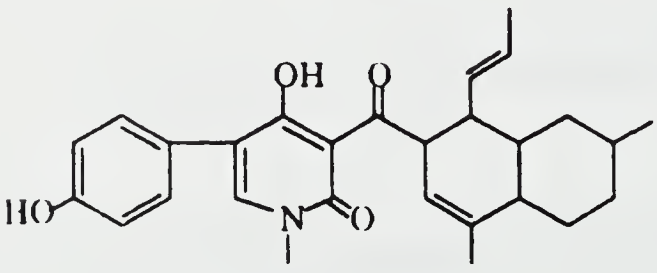
XLIII



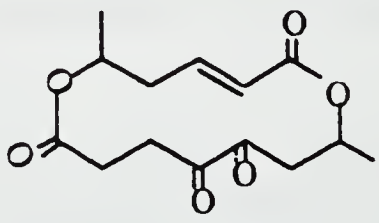
XLII. oudemansin B



XLIV, 3-mrthyl-
lumichrome



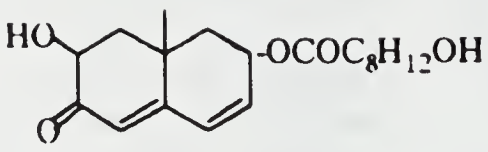
XLV, ilicolin H



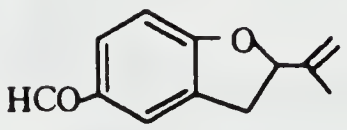
XLVI, grahamimycin A

Table IV Colored metabolites of fungi isolated from wood and/or trees.

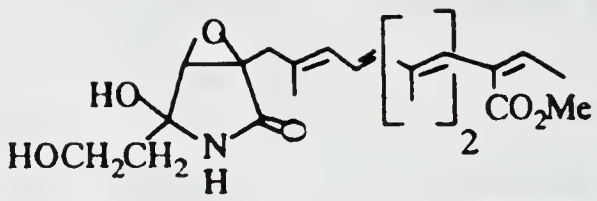
Fungal genus[1]	Number of: Isolates[2]	mycotox spp. on entries	mycotox[3]	Metabolite(s)[5]	References[6]
Acremonium	3 (3)	12	2[4]	I, R=Me, R'=(I, R=Me)	Divekar et al., 1959
				lolitrems	Gallagher et al., 1985;
				XXXI	Teshima et al., 1991
AGARICUS	1 (1)	23	1	XXXII	Levenberg, 1964
Agrocybe	1 (1)	7	1[4]	XXXIII, R=H	Ohenoja et al., 1987
Albatrellus	3 (2)	3	1[4]	I, R=4-HOC_6H_4	Besl et al., 1989
Alternaria	12 (3)	107	2	XVII, XIX	Pero et al., 1973;
				altertoxins *cf* XVI	Stinson et al., 1982; Hradil et al., 1989
Amanita	3 (3)	31	1[4]	XXXIV	Bayer & Kneifel, 1972
ANTHRACOPHYLLUM	1 (1)	3	1[4]	VII	Jägers et al., 1987
Anthrodia	27 (7)	1	1	$R(C{\equiv}C)_3H$	Barley et al., 1987
APHANOCLADIUM	2 (1)	1	1[4]	I, R=Me, R'=(I, R=Me)	Haessler et al., 1983
Armillaria	38 (2)	16	1	abietic acids	Ayer & Macaulay, 1987
Aspergillus	8 (8)	392	8	XI XII XX XXIII	1, 2, 3, 4
				XXX XXXV	5, 6, 7
				emodin	
Aureobasidium	15 (1)	3	1	depsipeptides	Takesako et al., 1991
Bjerkandera	10 (2)	1	1[4]	XXXVI	de Jong et al., 1992
Botrytis	2 (1)	16	1	XXXVII	Fehlhaber et al., 1974
Byssochlamys	3 (2)	8	2	XXXVIII	Baldwin et al., 1965
Cephalosporium	1 (1)	27	1[4]	*cf* IX	Tertzakian et al., 1964
Ceratocystis	25 (13)	15	5	XXIX	Ayer et al., 1987 Hanssen & Abraham, 1988
Chaetomium	8 (6)	59	2	I, R=5-prenyl-indolyl-3	Jerram et al., 1975
CHRYSOSPORIUM	1 (1)	6	1	XXXIX	Tsipouris et al., 1990
Cladosporium	9 (6)	15	2	XXX	Grove, 1972; Iida et al., 1989
CLAVICORONA	1 (1)	1	1	XL	Erkel et al., 1991
CONIOTHRYRIUM	1 (1)	1	1[4]	XLI	Krohn et al., 1992
Coriolus	36 (3)	5	1		Wada et al., 1975
CRUCIBULUM	1 (1)	1	1[4]	XLIII	Yoshida et al., 1990
Cryptosporiopsis	1 (1)	2	1[4]		Benz et al., 1974
Cyathus	16 (8)	17	2	XLIV	Ayer & Paice, 1976; Ayer et al., 1984
Cylindrocarpon	3 (3)	7	1[4]	XVIII	Coombie et al., 1972
Cylindrocladium	3 (2)	7	1	XLV	Tanabe & Urano, 1983
Cytospora	3 (2)	1	1[4]	XLVI	Ronald & Gurusiddaiah, 1980
DENDRYPHIELLA	1 (1)	5	1	XLVII	Guerriero et al., 1988
EMERICELLOPSIS	1 (1)	9	1	penicillins	Cole & Rolinson, 1961
ENDOTHIA	1 (1)	1	1	$C_{13}H_{14}O_5$	Boller et al., 1957
Epicoccum	9 (2)	8	2	IX	Baute et al., 1978;
				XXV	Raistrick & Rudman, 1956



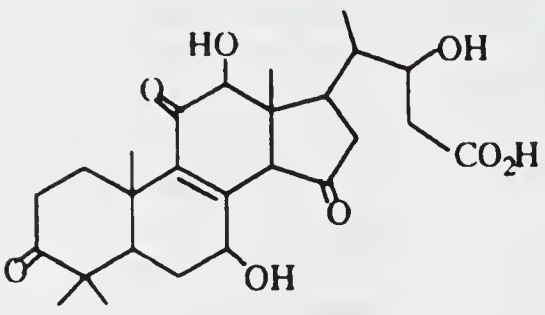
XLVII. dendryphiellin



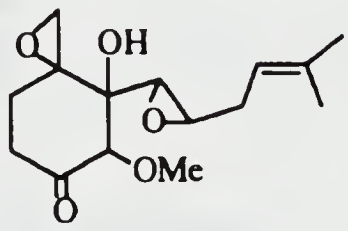
XLVIII, fomannoxin



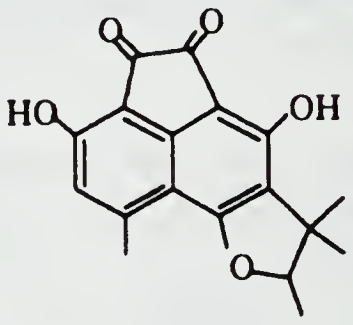
XLIX, fusarin C



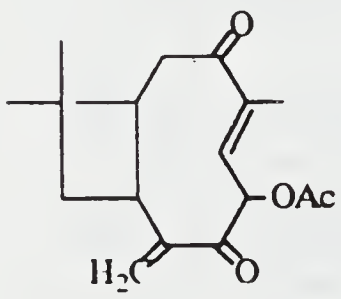
L. lucidenic acid A



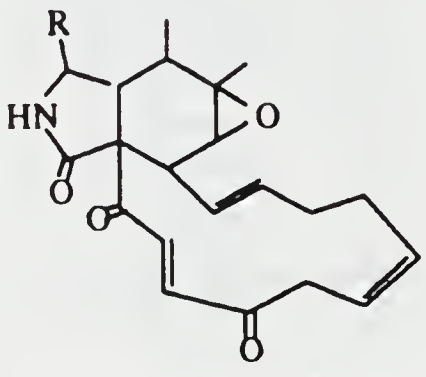
LI, graphinone



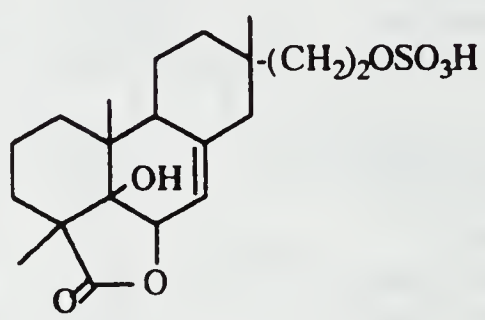
LII, sclerodione



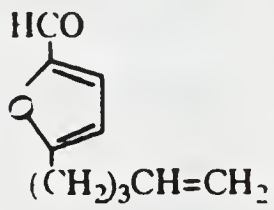
LIII. naematolone



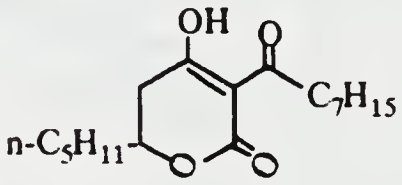
LIV, R=C_9H_8N=chaetoglobosins
R=C_7H_7=cytochalasins



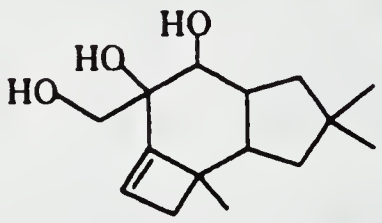
LV, hymatoxin



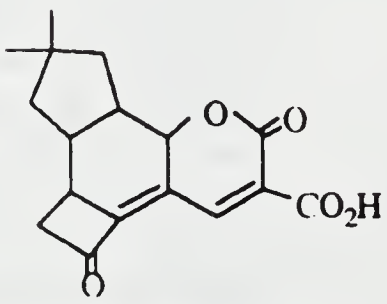
LVI



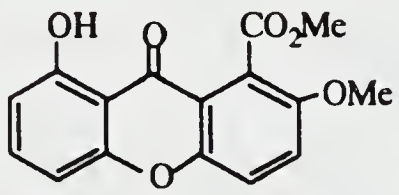
LVII, lachnellulone



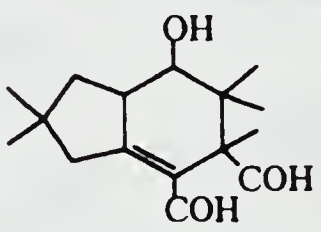
LVIII, armillol



LIX, lentinellic acid

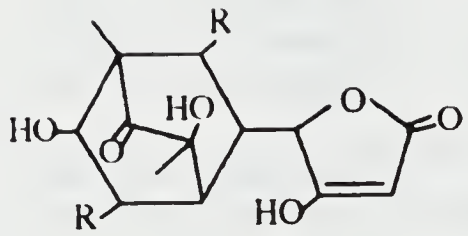


LX, mycoxanthone

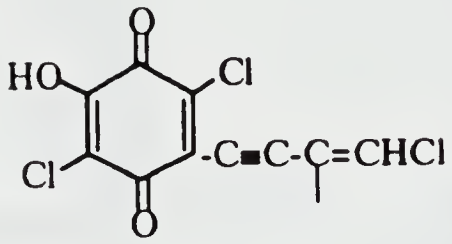


LXI, merulidial

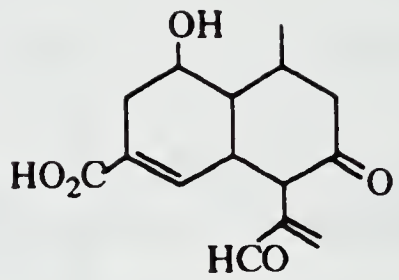
Flammulina	8 (3)	2	1	emitamin-2	Yamamoto & Ikegawa, 1978
Fomes	73 (17)	13	1	$H(C{\equiv}C)_3H$	Glen et al., 1966;
				XLVIII	Donnelly et al., 1980 ?
Fusarium	13 (5)	330	3	XLIX	Bushnell et al., 1984;
				XXI, X→Y	Gelderblom et al, 1984;
				$C_6H_9O_5$	
				XIII	Arnstein & Cook, 1947
Ganoderma	23 (10)	33	2	L, & congeners	Nishitoba et al., 1986; 1989
Gliocladium	6 (3)	26	3	X, XI	Leigh & Taylor, 1976; Howell & Stipanovic, 1983
				LXXXIX[7]	Packter & Steward, 1967
Gloeophyllum	17 (3)	5	1		Nakajima et al., 1976
Graphium	2 (2)	1	1[4]	LI	Sassa et al., 1970
Gremmeniella	37 (1)	6	1	LII, & dimers	Ayer et al., 1986
Gymnopilus	3 (2)	1	1	XXXIII	Heim et al., 1960
Hericium	27 (6)	3	1	$C_{19}H_{23(24)}O_5$	Kawagish et al., 1993
Heterobasidion	3 (1)	3	1	XLVIII	Sonnenbichler et al., 1983
HUMICOLA	2 (2)	2	1	$C_{19}H_{19}N_2O_8Na$	Nishikawa et al., 1991
HYALODENDRON	1 (1)	3	1[4]	III, R=C_6H_5, R'=OH	Strunz et al., 1973
Hygrophoropsis	1 (1)	3	1	IV, R=OH	Beaumont et al., 1968; Bresinsky & Bachmann, 1971
HYPHOLOMA	1 (1)	6	1	LIII	Backens et al., 1984
Hypoxylon	20 (15)	15	3	LIV	Beno & Christoph, 1976;
				serpenone[7]	Anderson et al., 1982;
				LV	Borgschalte et al., 1991
Inonotus	39 (12)	1	1	*cf.* L[7]	Kahlos, 1986
Irpex	11 (2)	3	2	LVI	Hayashi et al., 1981
Junghuhnia	7 (2)	1	1	LXXXVII	Gehrt et al., 1998
Lachnellula	2 (2)	2	1	LVII	Ayer & Villar, 1985
Laurilia	5 (1)	3	1	LVIII	Arnone et al., 1992
LECYTHOPHORA	1 (1)	1	1	$C_{43}H_{59}O_{19}SNa$	Ayer & Kawahara, 1995
Lentinellus	5 (3)	7	2	LIX	Hanssen & Abraham, 1986
Lentinus	11 (5)	20	2	$R(C{\equiv}C)_3H$	Abraham et al., 1988; Ahmed et al., 1978; Yasumoto et al., 1971
Leptographium	5 (2)	12	1	LX	Ayer et al., 1989; Abraham et al., 1986; Assante et al., 1979
Leptosphaeria	2 (2)	7	2[4]	LXXXVI	Itoh et al., 1990; White et al.,
				XVIII, R=H	1989
Merulius	13 (8)	1	1	$R(C{\equiv}C)_3H$	Gardner et al., 1960;
				LXI	Giannetti et al., 1986
Monilia	1 (1)	7	1[4]	4-hydroxybenzald-ehyde & others	Arinbasarov et al., 1988
Monilinia	3 (2)	12	1	XXII	Sassa et al., 1983; *idem* 1985



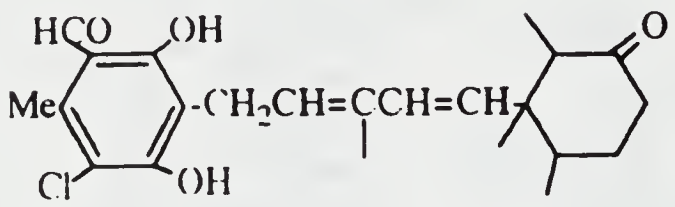
LXII, trichtetronine
R=CO(CH=CH)$_2$Me



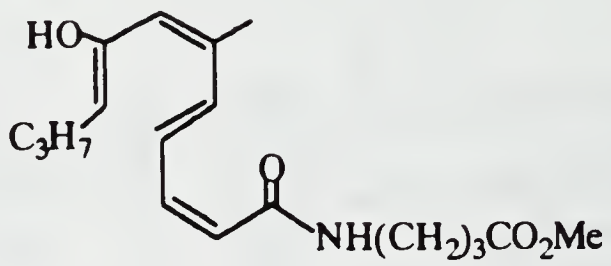
LXIII, mycenon



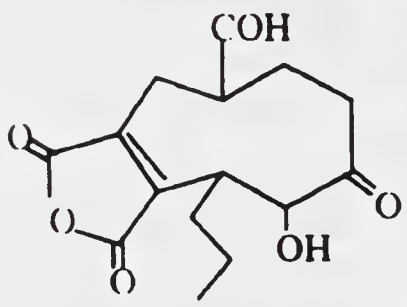
LXVII, panal



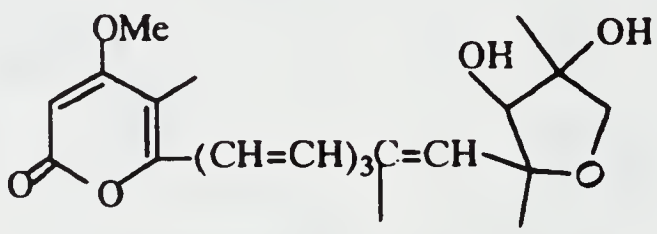
LXIV, ascochlorin



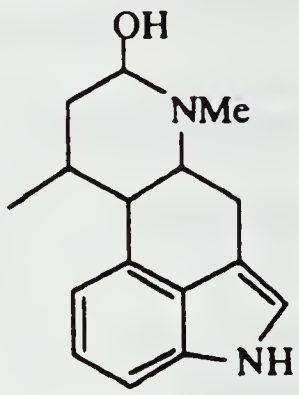
LXVI, variotin



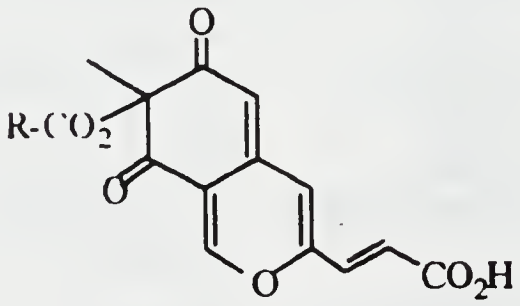
LXV, comexistin



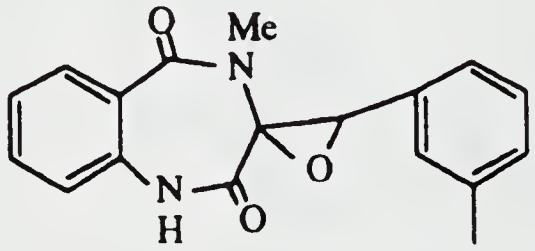
LXVIII, citreoviridin



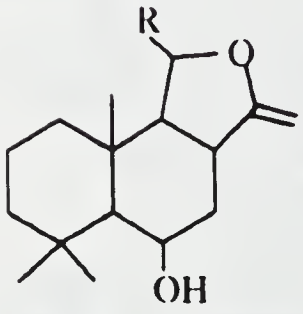
LXXI, roquefortines



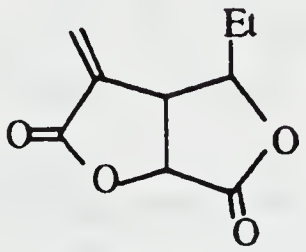
LXIX, mitorubionic acids



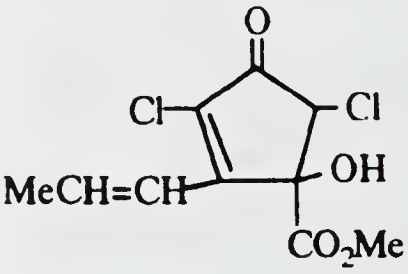
LXX, cyclopenin



LXXII, pereniporins

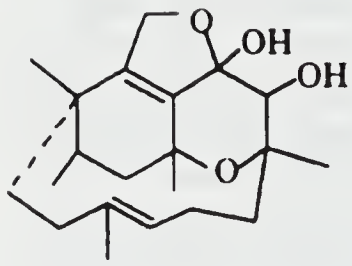


LXXIII, 4-epiethiosolide

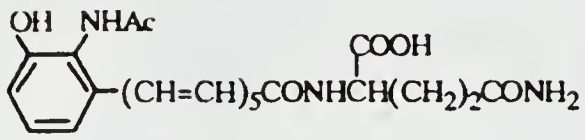


LXXIV, cryptosporiopsin

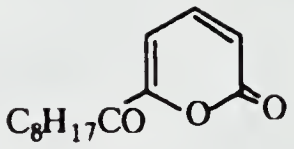
Monocillium	2 (1)	8	1	XII	Pusey & Roberts, 1963;
				XXIII	Bullock et al., 1962
MORTIERELLA	2 (2)	3	1[4]		Takahashi, 1961
Mucor	3 (3)	8	1	C_2H_4	Lynch & Harper, 1974
Mycena	3 (3)	6	1[4]	LXIII	Hantzel et al., 1990
Naematoloma	3 (3)	3	2	LIII	Backens et al., 1984;
				fasciculol *cf* L	Takahashi et al., 1987
Nectria	19 (13)	23	3	I, R=Me	Ayer & Shewchuk 1986;
				LXIV	Aldridge et al., 1972
OMPHALOTUS	1 (1)	2	1	IV, R=H, VI	Singh & Anchel, 1971;
					Bresinsky et al., 1974;
					Morisaki et al., 1985
Ophiostoma (≈ *Ceratocystis*)					
Oudemansiella	3 (3)	9	2	XLII, oudenone	Anka et al., 1979;
					Umezawa et al. 1985
Paecilomyces	5 (3)	32	3	LXV	Sumiki et al., 1959;
				LXVI	Fields et al., 1996
Panellus	6 (3)	1	1	LXVII	Nakamura et al., 1988
Panus	3 (2)	2	1	VIII	Kis et al., 1970
Paxillus	5 (3)	9	2	I, R=4-HOC_6H_4	Brewer et al., 1977;
					Holzapfel et al., 1989
Penicillium	33 (31)	357	20	emodin XIV LXX	8 9 10
				LXVIII LXIX LXXI	11 12 13
Peniophora	92 (35)	11	3	II	Gripenberg, 1958;
				V	Gripenberg &
					Martikkala, 1970
Perenniporia	19 (5)	3	1	LXXII	Kida et al., 1986
Pestalotia	1 (1)	5	1[4]	LIV, R=C_7H_7	Burres et al., 1992
Pezicula	1 (1)	6	1[4]	LXXIII (+)LXXIV	Schulz et al., 1995
					Stillwell et al., 1969
Phellinus	53 (18)	8	1	heptanones[7]	Serck-Hanssen &
					Wikström, 1978
Phialophora	33 (13)	9	1	XXVII –LXXIV	Aldridge et al., 1974
					Lousberg et al., 1976
Phlebia	18 (13)	1	1	LXI	Quack et al., 1978
Phoma	3 (3)	55	1[4]	$C_{35}H_{46}O_{14}$	Jones et al., 1992;
				LXXV	Sugano et al., 1991
Phomopsis	6 (3)	18	1[4]	LIV, R=C_7H_7	Izawa et al., 1989
PHYSARUM	1 (1)	1	1	LXXVI	Steffan et al., 1987
Pleurotus	30 (10)	7	2	R(C≡C)$_3$H	Gardner et al., 1960
Polyporus	87 (53)	33	3	ergosterols *cf* L	Valisolalao et al., 1983
Poria	116 (37)	13	2	R(C≡C)$_3$H	Gardner et al., 1960;
					Cambie et al., 1963
Potebniamyces	2 (2)	5	1	LXXVII	Poulton et al., 1979
Rhizoctonia	1 (1)	10	1	LXXVIII	D'Silva & Herrett, 1971
Rosellinia	3 (3)	2	1	LIV, R=C_7H_7	Kimura et al., 1989
Schizophyllum	6 (1)	3	1	indigo	Miles et al., 1956
Scytalidium	13 (5)	3	2	XXVII	Aldridge et al., 1974;
					Geigert et al.,1975
Serpula	12 (3)	2	1	R(C≡C)$_3$H	Farrell et al., 1987
Sporothrix	2 (2)	2	1[4]	$C_{33}H_{48}O_{10}$	Nakanishi et al., 1989
Stachybotrys	2 (2)	15	1	*cf* XXVI	Eppley et al., 1977;
				LXXIX	El-Kady et al., 1988
Stemphyllum	1 (1)	12	1[4]	$C_{15}H_{22}O_2$[7]	Sassa et al., 1988
Stereum	33 (17)	12	3	XVIII, R=CHO	Orr, 1979
				LXXXVI	Xie et al., 1992



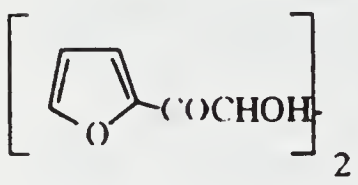
LXXV. phomactin A



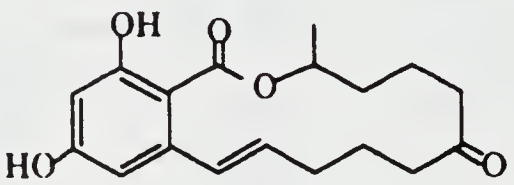
LXXVI, physarochrome



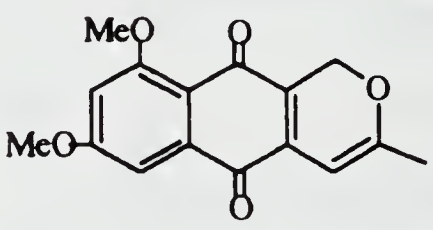
LXXVII, phacidin



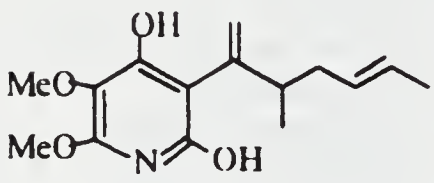
LXXVIII. rhizosolaniol



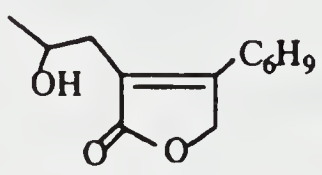
LXXIX, zearalenone



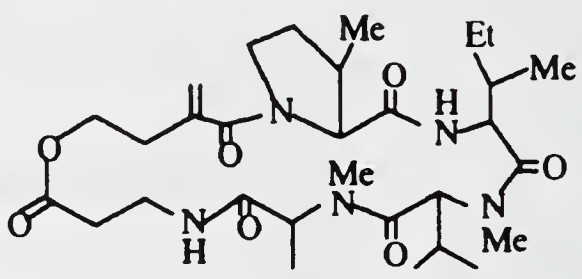
LXXX, herbarin



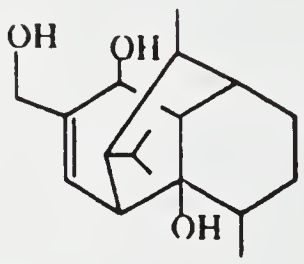
LXXXI. harzianopyridone



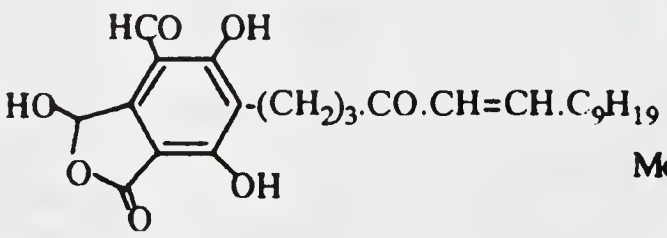
LXXXII, harzianolide



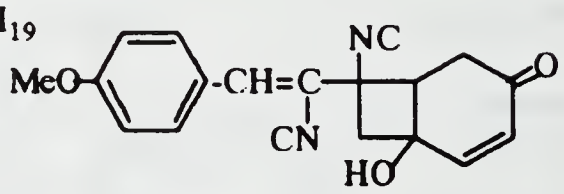
LXXXIII, roseotoxin=destruxin



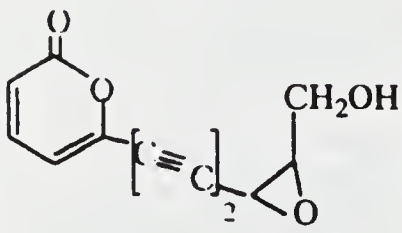
LXXXIV. vinigrol



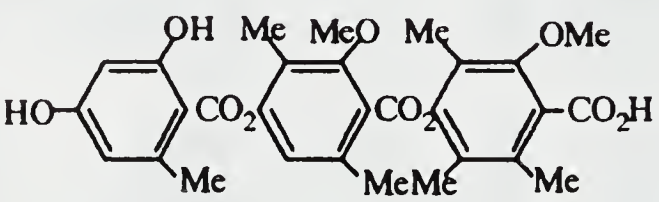
LXXXV



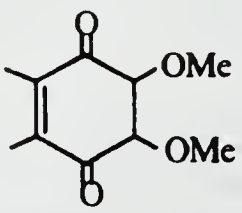
LXXXVI



LXXXVII. nitidon



LXXXVIII, thielavin(s)



LXXXIX, gliorosein

Suillus	3 (3)	6	1	I, R=H, R'=($C_{20}H_{33}$)	Beaumont & Edwards, 1969; Jägers et al., 1986
Talaromyces	6 (5)	12	2	emodin skyrin=diemodin	Tatsuno et al., 1975; Bachmann et al., 1979
Thielavia	2 (2)	1	1	LXXXVIII	Rothstein et al., 1998
TORULA	1 (1)	1	1	LXXX	Kadkol et al., 1971
Trametes	29 (16)	3	2	II	Gripenberg, 1958
Trichoderma	60 (19)	117	9	I, R=R'=H XI XV XX XXIV, R=CO_2H LXXXI LXXXII	14 15 16 17 18 19 20 21
Trichothecium	1 (1)	7	1	LXXXIII LXII	Springer et al., 1984
Ulocladium	3 (3)	3	1	$C_{21}H_{30}O_3$ = ulocladols A & B	Sviridov et al., 1991
Verticicladiella	7 (6)	3	1[4]	XII	Ayer et al., 1983
Verticillium	6 (2)	38	2		Ayer & McCaskill, 1981
VIRGARIA	1 (1)	2	1	LXXXIV	Ando et al., 1988
Xylaria	7 (6)	6	1	LXXXV	Gunawun et al., 1990
ZALERION	3 (1)	3	1	ergosterol	Block et al., 1973; Kirk & Catalfomo, 1970

[1] Fungal substrates are indicated thus: names in italics are from from the woody parts of trees and from wood of undefined botanical origin; those in upper & lower case are from trees only and those in capitals are from wood products only (at least as far as the collection data is concerned).

[2] "Isolates" refers to the number of specimens kept in the culture collection; numbers in parentheses are the number of species of this genus held in the collections.

[3] Numbers of species in the collections of the genus also found in the mycotox file.

[4] Indicates no congruence of species in the mycotox file with species in the collections, but fungi classified only to the genus level in the mycotox file are found fully classified in the collections. These genera are included because of the possibility of identity at the species level.

[5] Roman numerals refer to structural formulae in the text.

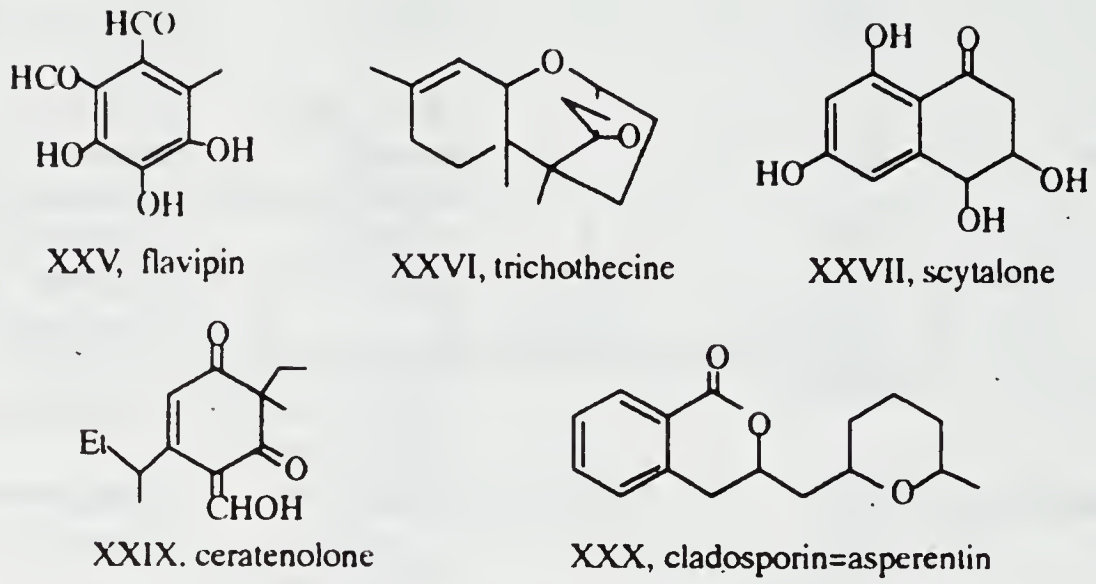
[6] References to metabolites of *Aspergillus, Penicillium & Trichoderma* as follows:

1 Pusey & Roberts, 1963
2 Asao et al., 1963
3 Burkhardt & Forgacs, 1968
4 Slater et al., 1967
5 Yu et al., 1967
6 Gorst-Allman & Steyn, 1980
7 Leigh & Taylor, 1976
8 Tatsuno et al., 1975
9 Cole et al., 1983
10 Mohammed & Luckner, 1963
11 Sakabe et al., 1977
12 Quick et al., 1980
13 Natsume et al., 1985
14 Taylor, 1986
15 Kamal et al., 1971
16 Bertina, 1987
17 Andrade et al., 1992
18 Dickinson et al., 1989
19 Claydon et al., 1991
20 Grove et al., 1966
21 Shirota et al., 1997

[7] Structure given in paper title.

The preservation of wood

In view of the durability of wood it might seem superfluous to review anthropomorphic attempts to improve its longevity. It has been known for centuries that wood kept dry and well-ventilated will not deteriorate. Nevertheless, wood is biologically unstable and this has been recognized, for example, by the preservation of pilings with bitumen, the hardening of beech with boiled linseed oil and even the use of cationic detergents (Zabielska-Matijuk et al., 1995). Our purpose in this review is not with preservation of this sort, but rather with the possibility of understanding and thus enhancing the mechanisms whereby wood achieves its stability. This understanding will be dependent on the biochemistry described in the two preceding sections.



XXV, flavipin XXVI, trichothecine XXVII, scytalone

XXIX. ceratenolone XXX, cladosporin=asperentin

Fig 8 Further characteristic metabolites of fungi isolated from wood.

Fifty years ago (Brian, 1944) it was thought that fungal metabolites that had marked antifungal and antibacterial action *in vitro*, such as gliotoxin (Fig 3, XI) and the trichothecins (Fig 8, XXVI) might be used as preservatives but this idea was abandoned because of the cost of these metabolites. However in the last decade or so, opportunities of evading such restrictions have emerged. We propose to review these possibilities critically in the following sections. They stem from an increasing appreciation of the lichenous nature of vascular plants (e.g. Ogawa & Kanada, 1984), an improved understanding of the endomycorrhizal populations of trees and some success in manipulating the genome of plants to increase their resistance to pathogens (e.g. Thomas & Kenerley, 1989). Additionally the long known fungistasis of soil (Lingappa & Lockwood, 1961) may be pertinent to this discussion because the growth of soil fungal populations are controlled by mechanisms that may be similar to those affecting the mycobiont populations of trees.

Fungi reported to be effective biocontrol agents

Table V Fungi used as agents to potentially control invasion of trees and wood products by pathogenic fungi

Growth controlling fungus	Growth inhibited organism	Host Plant	Possible metabolite	References
Athelia bombacina	*Venturia inaequalis*	*Malus* sp.		Miedtke & Kennel 1990
Cerrena meyenii	*Rigidoporus lignosus*	*Hevea brasiliensis*		Sudirman et al., 1992
Cheatomium globosum	*Venturia inaequalis*	*Malus* sp	chetomin	Cullen & Andrews 1984
-	*Pythium ultimum*			Walther & Gindrat 1988
Cladosporium cladosporioides	*Perenospora arborescens*			Nigam & Rai 1988
Fusarium oxysporum	*Paxillus involutus*			Farquhar & Peterson, 1990

Geophyllum striatum	*Rigidoporus lignosus*	*Hevea brasiliensis*		Sudirman et al., 1992
Gliocladium roseum	*Alternaria alternata*			Turham 1993
-	*Verticillium dahliae*			Keinath et al., 1991
-	*Ceratocystis* sp.	*Tsuga* sp., & *Abies* sp.		McAfee & Gignac 1997
Gliocladium virens	*Botrytis cinerea*			Phillips 1986
-	*Corticum rolfsii*			Artigues & Davet 1984
-	*Phellinus weirii*	*Pseudotsuga* sp.		Nelson et al., 1987
-	*Pythium ultimum*		XI	Roberts & Lumsden 1990
-	*Gloeophyllum trabeum*	*Acer* sp. & *Pinus* sp.		Highley et al , 1997 Highley, 1997
-	*Irpex lacteus*	-	?XI	-
-	*Neolentinus lepideus*	-		-
Gliocladium virens	*Phebia brevispora*	-		Highley, 1997
	Postia placenta	-		-
-	*Trametes versicolor*	-		-
Lecythophora hoffmannii	*Ophiostoma crassivaginatum*	*Populus tremuloides*		Chakravarty & Hiratsuka, 1994
Lentinus squarrosulus	*Rigidoporus lignosus*	*Hevea brasiliensis*		Sudirman et al., 1992
Nectria inventa	*Alternaria alternata*			Turham 1993
Paecilomyces lilacinas	*Aspergillus flavus*			Will et al., 1994
Phaeotheca dimorphospora	*Armillaria sp.*	*Ulmus* sp.		Yang et al., 1993
	Heterobasidion annosum			Yang et al., 1993
-	*Nectria galligena*	-		Yang et al., 1993
-	*Ophiostoma ulmi*	-		Yang et al., 1993
Pythium oligandrum	*Pythium* sp.			Foley & Deacon 1986 Walther & Gindrat 1987
Scytalidium album	*Fomes annosus*	*Picea abies*		Lundberg & Unestam 1980
-	*Macrophomina phaseolina*	*Vigna mungo*		Shahzad et al., 1991
Sporormiella similis	*Ophiostoma piliferum*	*Populus tremuloides*	tiglic acid	Chakravarty et al., 1994
Trichoderma hamatum	*Corticum rolfsii*			Artigues & Davet 1984
-	*Pythium ultimum*	*Pisum* sp.		Reyes & Dirks 1985
-	*Trichoderma pseudokoningii*			Vajna 1985
Trichoderma harzianum	*Fomes annosus*	*Picea abies*		Lundberg & Unestam 1980
-	*Fusarium oxysporum*	*Pseudotsuga menziesii*		Mousseaux et al., 1998
-	*Lentinus edodes*			Tokimoto 1982
-	*Macrophomina phaseolina*	*Citrullus* sp.		Elad et al., 1986

-	*Phellinus noxius*			Tong-Kwee & Keng 1990
-	*P. weirii*	*Pseudotsuga menziesii*		Nelson et al., 1987 Goldfarb et al., 1989
Trichoderma citrinoviride	*Armillaria ostoyae*	*Pinus* sp.		Reaves et al., 1990
Trichodema viride	*Armillaria* mellea			Dubos et al., 1978
-	*Armillaria ostoyae*	*Betula verrucosa*		Kwasna, 1996
-	*Armillariella mellea*			Dubos et al., 1978
-	*Crinipellis perniciosa*	*Theobroma cacao*		Bastas 1988
-	*Fomes annosus*			Sierota, 1977
-	*Fusarium oxysporum*			Reyes 1984 Cherif & Benhamon 1990
-	*Laccaria bicolor*	*Picea mariana*		Summerbell 1987
Trichoderma viride	*Phellinus weirii*			Nelson & Thies 1986
-	*Ustulina deusta*	*Fagus sylvatica*		Mercer & Kirk 1984
Trichoderma sp.	*Anthrodia carbonica*			Highley & Richard 1988
-	*Corticum rolfsii*			Naito & Obara 1985
-	*Ganoderma boninense*			Tong-Kwee & Keng 1990
-	*G. phillippi*			Tong-Kwee & Keng 1990
-	*Panellus stypticus*			Bemudes et al., 1991
-	*Phomopsis sclertioides*			Vanachter et al., 1988
-	*Postia placenta*	*Pseudotsgua menziesii*		Dawson-Andoh & Morrell 1991
-	*Rigidoporus lignosus*			Tong-Kwee & Keng 1990
-	*Rosellinia necatrix*	*Amygdalus communis*		Freeman et al., 1986
Verticillium dahliae	*Ophiostoma ulmi*	*Ulmus capinifola*		Scheffer 1990
Zygorhynchus moelleri	*Fusarium oxysporum*		Indole-3 ethanol	Brown & Hamilton 1992
-	*Armillaria ostoyae*	*Betula verrucosa*		Kwasna, 1996

Table V is an attempt to summarize work on the use of fungi given in column 1 to retard the growth of other fungi (column 2) commonly found on wood and trees (Table I). This substrate (phycobiont) is given, when reported, in the third column of Table V.

The criteria of selection of entries in Table V are that the agent potentially exerting control and the parasite affected should be fungi and that one or other or both should have been reported as mycobionts of trees. Twenty three species of fungi and one classified only to the genus level are given in column 1 of Table V. These organisms have been reported to control the growth of one or more of the 39 species or genera give in column 2 of the Table. Thirty two (82%) of the latter are inhibited by

anamorphic manifestations of the Hypocreaceae. This predominance may reflect a characteristic function of this group of fungi, but it is also possible that they are merely conceived to be the easiest to study ! Recently a treatise (Kubicek and Harman, 1998) on some aspects of the biology of the Trichoderma and Gliocladium genera has ben published. Volume 2 of this treatise (Hjeljord and Tronso, 1998) emphasizes the scientific underpinning of biocontrol technology by investigations such as those described in the preceding sections of this review. The treatise contains a summary of the excellent Israeli studies of the ultrastructure of the changes that occur during mycoparasitism and also of the biochemical mechanisms that induce lysis of the host (pathogenic to the plant) fungus (Chet et al., 1998). The antibiosis aspect of mycoparasitism is less adequately treated.

A good deal of work has been done on methods of establishing the biocontrol agent in the host (Lundberg & Unestam, 1980; Garbaye & Bowen, 1989). and in particular the formulation of the agent. Several papers have appeared reporting the merits of associating the potentially controlling fungus, in aliginate pellets (Lewis & Papavizas, 1985; Lumsden *et al.*, 1992), bran matrices Lewis & Papavizas, 1987; Roiger & Jeffers 1991), bark (Nelson & Hoittink, 1983) and a variety of other better characterized. polysaccharides (Lewis et al., 1996; Mihuta-Grimm & Rowe, 1986; Rodeia, 1994). Related to this work is the known proportional increase of activity with the chitin content of the cell wall of the plant pathogen (Lorito et al., 1993). The role of insects has been investigated, particularly in connection with black stain disease (*Ophiostoma minus, Leptographium wingfieldii* & *Ceratocystis piceae*) where a vehicle of fungal dissemination is thought to be the beetles (*Hylastes macer*, Goheen & Cobb, 1978; *Xyloterus lineatus*, Babuder & Pohleven, 1997), though by contrast bees (*Rubus idaeus, Apis mellifera*) have been used as carriers of *Gliocladium roseum* in biocontrol experiments (Peng *et al.*, 1992; Yu, 1996). Associated with many of these techniques is the question of rhizosphere competence (Thuy, 1991) i.e. the ability of the biocontrol agent to survive in the root ecosystem.

Possibly related to the problem of establishing mycocontrol agents is the use of the reported synergism of the Endogonaceae with *Trichoderma* spp. (Calvet *et al.*, 1992; Koehl & Schoesser, 1989; Rousseau *et al.*, 1996) and with *Aspergillus niger* (Mcallister *et al.*, 1995). It has been reported (Poulin *et al.*, 1993; Harrison & Dixon, 1993) that flavanoid metabolites, commonly produced by the fungi in Table I (Hemingway *et al.*, 1977; Ayer *et al.*, 1987) stimulate the formation of endomycorrhiza by e.g. *Glomus* spp. but this observation has been disputed (Becard *et al.*, 1995).

Potential hazards of biocontrol

The deliberate introduction of a fungus into the tree ecosystem with the object of controlling manifestation of part of that system is a procedure that can be justified only on the basis of much experimental knowledge. It is very difficult to forecast the chemical and biological properties of the metabolites produced by any particular isolate grown on an ill-defined medium. A great deal of work has been done in the last 60 years on the use of *Gliocladium virens* (Table V) as a control organism (Weindling, 1932) and the mechanism of its inhibitory action has been studied (e.g. Jones & Hancock, 1988; Ridout & Lumsden, 1993; Wilhite & Straney, 1996). Initially, gliotoxin (Fig 3, XI) was considered to be the agent responsible for biocontrol but a belated review of the literature led to the suggestion of other possibilities e.g. viridin (Fig. 4, XV) and gliovirin (Fig 3, X). Another proposed control agent, *Stachybotrys cylindrospora*, which produces trichothecins (e.g. XXVI, Fig 7) is thought to inhibit stain formation in *Populus* spp. (Hiratsuka *et al.*, 1994).

All of this work rests on the belief that antimicrobial activity at low concentration *in vitro* is a realistic measure of the effectiveness of the biocontrol agent *in vivo*; experimental confirmation in trees is unproven and is, necessarily a long term undertaking. Even when and if a biocontrol agent is proved to be effective in the field, other possible disadvantages of the agent need to be considered. Many of the potential biocontrol agents in Table V are known to produce toxic volatile metabolites (Hanssen & Abraham, 1986, 1988; Gopinath & Shetty, 1988; Dean *et al.*, 1989). These metabolites include cladosporin (Fig 8, XXX, Grove, 1972), the C_8 isocyanides e.g. XXIV, R=H, Fig 6, of *Trichoderma* spp. (Fujiwara *et al.*, 1982; Boyd *et al.*, 1991) and the possibly related avenaneol (Nair *et al.*, 1982). Such volatile metabolites are a potential hazard to those exposed to wood during manufacture and later in the use of the products made with it (Hendry & Cole, 1993; Larsen et al., 1998). The hazard is, however, not confined to volatile toxins for exposure to sawdust has been reported to induce toxicosis (Simeray et al., 1997).

Discussion

The organisms tabulated in Table I cannot be regarded as a characteristic sample of the Northern temperate forest because it is obvious from Table II that they have not been isolated from areas selected at random. In addition the fungi represent only those organisms that have proved capable of laboratory cultivation. Possibly a better sample would have been obtained had the extensive herbarium holdings of the collections been included. For these reasons cluster analysis of the data in Table I was not justified. Despite these reservations the diversity and richness of this fraction of the forest fungal population is impressive and it represents years of enthusiastic collections by dedicated mycologists on the look-out for new and interesting specimens. Its extension probably depends on continuing documentation by students of forest ecology.

There is a growing appreciation of the possibility of using a biological process to achieve purification of cellulose from wood, one attraction being the conversion of lignin into readily digested fodder. Some work on the use of *Phanerochaete* spp. for this purpose has been reported though in our opinion greater value may be obtained by designing the digestion to produce, in addition, valuable metabolites e.g. dyestuffs. The known production of benz-1,4-dione from lignin by these organisms is perhaps grounds for optimism. Nevertheless, there is a need for careful study of the action of well defined enzymes in the conversion of lignin to useful products that will enhance the profitability of the forest products industry.

There are a number of other highly colored metabolites produced by tree fungi that are not part of the collections used in this review e.g. *Piptoporus australiensis* which produces a group of 18-methyl-19-oxoeicosahexaenoic acids (Gill, 1982).

The prospects for selecting endomycobionts to protect trees and lumber from degradation is at once attractive but also fraught with undesirable consequences if pursued on an inadequate knowledge base. For example current beliefs in efficacy of antimicrobial agents depends on concentrations in solution, but in trees a peptaibol adsorbed on a cellulose fiber presents a local massive concentration gradient, dependent perhaps on the cellulose behaving as a template during its biosynthesis (Brewer et al., 1987). Such speculation has some support in the enhanced efficacy of biocontrol agents in an insoluble polysaccharide matrix (see above p 25). The study of such kinetic controls is of outstanding botanical interest and, we hope that this review will stimulate interest in this and related topics.

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Addendum

Synonymy of binominal names of fungi given in Tables

Alternaria tenuis = A. alternata
Athelia fuscostratum = Confertobasidium olivaceo-album
Ceratocystis multiannulata = Ophiostoma multiannulatum
Cladosporium resinae = Hormoconis resinae
Coriolellus albidus = Trametes sepium = Antrodia albida
Coriolus versicolor = Trametes versicolor
Corticium cremoricolor = Cerocorticium cremoricolor
Corticium vellereum = Hypochnicium vellereum
Corticium laeve = Cylindrobasidium laeve
Cylindrobasidium evolvens = Cylindrobasidium laeve
Cystostereum murraii = Cystostereum murrayi
Dacrymyces palmatus = Dacrymyces chrysospermus
Epicoccum purpurascens = Epicoccum nigrum
Fomes pinicola = Fomitopsis pinicola
Fomes roseus = Fomitopsis rosea
Gloeoporus pannocinctus = Ceriporiopsus pannocinctus
Gliocladium virens = Trichoderma virens
Hapalopilus nidulans = Hapalopilus rutilans
Hirschioporus abietinus = Trichaptum abietinus
Hirschioporus pargamenus = Trichaptum biforme
Hyphoderma heterocystidium = H. heterocystidia
Hyphoderma medioburiensis = H. medioburiense
Hyphoderma mutata = H. mutatum
Hyphodintia arguata = H. arguta
Lentinus lepideus = Neolentinus lepideus
Lenzites sapiaria = Gloeophyllum sepiarium
Leptodontidium elatius = Rhinocladiella elatior
Merulius armeniacus = Meruliopsis albostramineus
Merulius aureus = Pseudomerulius aureus
Merulius serpens = Ceraceomyces serpens

Merulius tremellosus = Phlebia tremellosus
Naematoloma sublateritinum = Hypholoma sublateritinum
Paxillus panuoides = Tapinella panuoides
Peniophora cremea = Phanerochaete sordida
Peniophora gigantea = Phanerochaete gigantea
Peniophora ludoviciana = Phlebia ludoviciana
Phialophora americana = P. verrucosa
Phlebia radiata = P. merismoides
Phlebia roumeguerii = Phlebiopsis roumerguerii
Pholiota spectabilis = Gymnopilus spectabilis
Pleurotus lignatilis = Ossicaulis lignatilis
Pleurotus serotinus = Panellus serotinus
Pleurotus ulmarius = Hypsizygus ulmarius
Polyporus compactus = Poria compacta = Perenniporia compacta
Polyporus conchifer = Poronidulus conchifer = Trametes conchifer
Polyporus lentus = Wrightoporia lenta[1]
Polyporus tulipiferae = Irpex lacteus
Polyporus versicolor = Trametes versicolor
Poria carbonica = Antrodia carbonica
Poria crassa = Antrodia crassa
Poria crustulina = Diplomitroporus crustulinus
Poria ferrea = Phellinus ferreus
Poria fissiliformis = Perenniporia fissiliformis
Poria griseoalba = Ceriporia viridans
Poria latemarginata = Oxyporus latemarginata
Poria overholtsii = Diplomitoporus overholtsii
Poria placenta = Postia placenta
Poria rhodella = Ceriporia viridans
Poria spissa = Ceriporia spissa
Poria subvermispora = Ceriporiopsis subvermispora
Poria vaillantii = Antrodia vaillantii
Poria xantha = Antrodia xantha
Potebniamyces coniferarum = Phacidium coniferarum
Radulodon casaerium = Radulodon americanus
Rigidoporus nigrescens = Rigidoporus crocatus
Rigidoporus sangquinolentus = Physisporinus sanguinolentus
Rigidoporus vitreus = Physisporinus vitreus
Serpula incrassata = Meruliporia incrassata
Serpula lacrymans = S. lacrimans
Sistotrema coronilla = S. brinkmannii
Sistotremastrum niveocremeum = Paullicorticium niveocremeum
Sporormiella = Preussia
Stereum complicatum = S. hirsutum
Stereum frustulosum = Xylobolus frustulatus
Talaromyces stipitatus = Penicillium stipitatum
Trametes scabrosa = Earliella scabrosa
Trechispora raduloides = Sistotrema raduloides
Tyromyces balsameus = Postia balsameus
Tyromyces caesius = Postia caesius
Tyromyces mollis = Leptoporus mollis
Tyromyces palustrus = Fomitopsis palustris
Tyromyces semisupinus = Antrodiella semisupina
Tyromyces serviceomollis = Postia serviceomollis
Tyromyces sprageui = Fomitopsis spraguei
Tyromyces stipticus = Postia stiptica
Tyromyces tephroleucus = Postia tephroleuca
Tyromyces undosus = Postia undosa
Vararia effuscata = Dichostereum effuscatum
Xenasma tulasnelloideum = Phlebiella tulasnelloidea

[1] This synonym is unceratin as the species appears to have mostly conifers as substrate while this entry comes from deciduous trees.

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Short Communications

BACCHARIS: A GENUS OF THE ASTERACEAE NEW TO CANADA

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This note reports the occurrence of GROUNDSEL-TREE or sea-myrtle, *Baccharis halimifolia* L. on islands at the mouth of Tusket river (43°46'N, 65°55'W), thus adding a new genus to the flora of Canada.

Cette observation rapporte la présence du séneçon *Baccharis halimifolia* L. sur les îles à l'embouchure de la rivière Tusket (43°46'N, 65°55'O) contribuant ainsi un nouveau genre à la flore du Canada.

Baccharis halimifolia L. is a dioecious shrub which grows one to three metres in height and forms thickets bordering the salt marshes of eastern North America. It has green, angled twigs with three bundle scars. Young stems are scurfy, as are the leaves, and are often dotted with resin. In the fall, the leaves and twigs tend to become dull greyish green, giving the plant a definite greyish hue when viewed from a distance. The leaves are alternately arranged. The lower ones are thick, two to five centimetres in length, diamond shaped and cuneately narrowed basally with short petioles. From the middle to the tip, their margins exhibit coarse, wave-like teeth. Leaves on the branchlets are often smaller and entire. The small, inconspicuous flowers appear in the latter part of August. They are mostly stalked or in distinctly stalked clusters. The fruits are small ribbed achenes, each with a silky white pappus.

I was alerted to the possible presence of this shrub in Nova Scotia by a chance meeting with John Brett of Halifax. John is an experienced cinematographer with a keen interest in nature. Several weeks later, on September 11, 1998, his father, Peter Brett, guided me to an area where the groundsel-tree was found to be growing in great abundance along the salt marshes and adjacent areas of Tête à Millie and Morris Islands (43° 46´N 65° 55'W) at the mouth of the Tusket River in Yarmouth County, Nova Scotia. The masses of white tufted achenes were conspicuous from a considerable distance. Close examination confirmed the identity of the shrub. I had become very familiar with this plant some years ago on an excursion to the Florida Panhandle.

The habitat of *Baccharis halimifolia* is shared by *Aronia melanocarpa, Ilex verticillata, Myrica pensylvanica,* and *Rosa virginiana*. Prior to this report, the known distribution of *Baccharis halimifolia* was from Florida (Godfrey, 1988) to Texas and Mexico north to the coast of Massachusetts. (Dwelly, 1980; Fernald, 1993). Further botanical exploration of southwestern Nova Scotia may well reveal a wider distribution of this striking shrub.

It is surprising that the presence of a species as large and conspicuous as *Baccharis halimifolia* has not been reported previously. Two possible explanations for this are that it blends in so well with other coastal shrubbery and/or the colonies are in a remote location. However two other southern shrubs, *Toxicodendron vernix* and *Clethra alnifolia,* are also relatively recent reports from this general area of the province (Roland and Zinck, 1998).

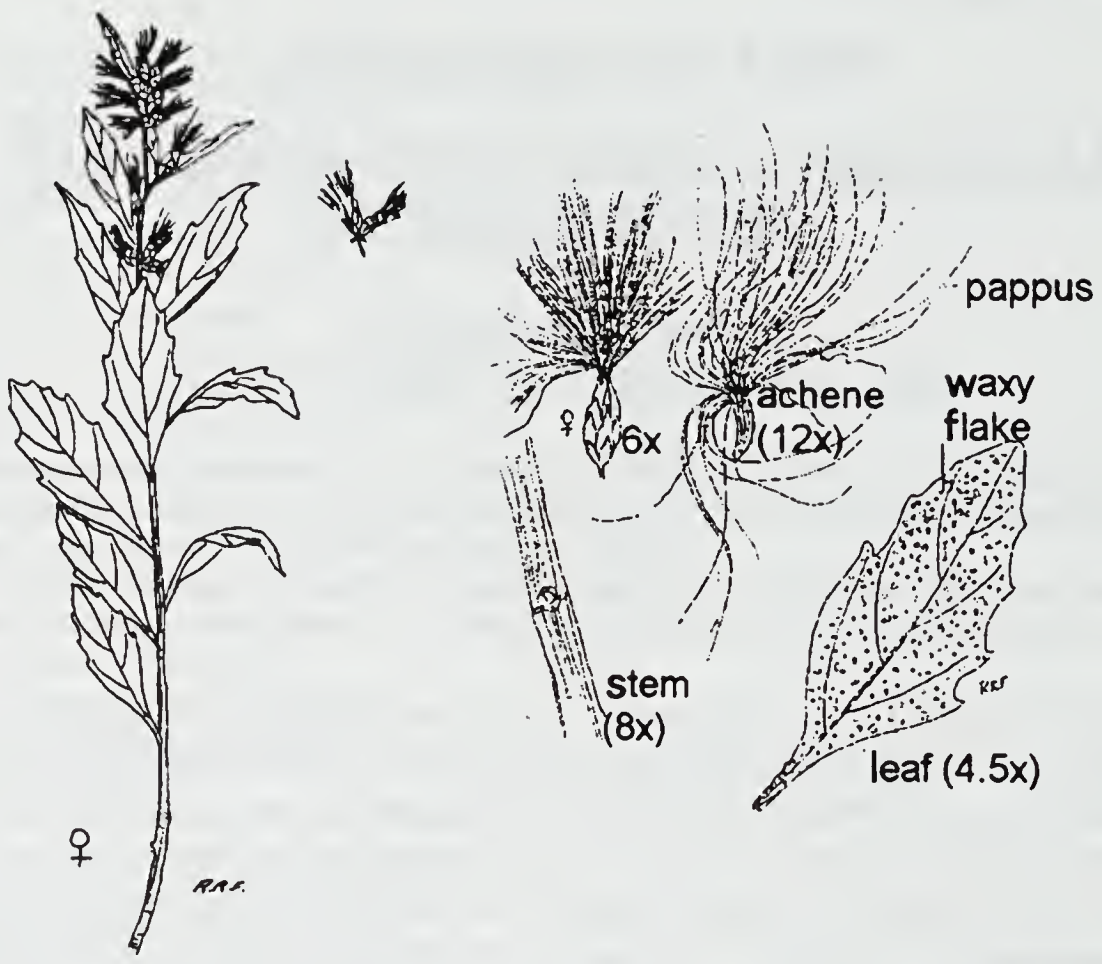

Fig 1 *Baccharis halimifolia* L. was collected for the first time in Canada on Morris and Tête à Millie Islands in Yarmouth County, Nova Scotia in September of 1998.

Voucher specimens have been deposited with the Nova Scotia Museum of Natural History, Halifax, Nova Scotia (NSPM); the Canadian Museum of Nature in Ottawa, Ontario (CAN); the Grey Herbarium of Harvard University, Cambridge, Massachusetts (GH); and the E.C. Smith Herbarium at Acadia University, Wolfville, Nova Scotia (ACAD).

I wish to acknowledge the contributions of my informants, John and Peter Brett, and of the Nova Scotia Museum of Natural History to this undertaking.

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OVERWINTERING *Leiobunum elegans* (OPILIONES: PHALANGIIDAE) IN CAVES AND MINES IN NOVA SCOTIA.

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The opilionid *Leiobunum elegans* was found overwintering in caves and mines in mainland Nova Scotia and Cape Breton Island. It occurred both as adults and near-adults, usually as single individuals or small clusters, but aggregations were formed at one site. It is suggested that aggregation formation is a behavioural adaptation for coping with saturated atmospheres. This is the first published report of overwintering opilionids in such habitats from eastern Canada.

L'opilionide *Leiobunum elegans* a été trouvé en hivernement dans des caves et des mines de l'Ile du Cap Breton et aussi de la Nouvelle-Écosse continentale. Ceci a eu lieu comme adultes ou quasi-adultes, ordinairement comme individus ou en petits groupes, mais des agrégations ont été trouvées à un seul lieu. On suggère que la formation d'agrégations est une adaptation de comportement afin d'endurer des atmosphères saturées. La publication de l'hivernement d'opilionides dans de tels habitats est la première ayant trait à l'est du Canada.

A number of opilionid species use underground cavities for overwintering, being found seasonally in the thresholds of caves and mines in northern temperate latitudes. Examples from Europe include *Amilenus aurantiacus* (Simon) and several other species (Martens, 1978). In North America, *Nelima paessleri* (Roewer) uses caves and mines in southwestern Canada for this purpose (Holmberg *et al.*, 1984) and *Leiobunum elegans* Weed, a widely distributed eastern species (Davis, 1934), is often reported in similar habitats in the United States (Brown, 1997). During overwintering, some species may form large aggregations of up to several thousand individuals. Holmberg *et al.* (1984) have reviewed the literature on this phenomenon.

We have found *Leiobunum elegans* overwintering in caves and mines in Nova Scotia. It was found in both mainland Nova Scotia and Cape Breton Island, seven of the ten winter collecting sites (five natural caves and two abandoned mineworkings) which were visited during a general faunal survey. It was found from October through to May usually in the deep threshold ("twilight zone") of the caves or mines, though an occasional specimen was taken within the dark zone. At most of the sites the species occurred as scattered individuals, or sometimes in small groups of up to twenty five. However, small aggregations were found in an abandoned mine adit at Tennycape (Hants County) known locally as Peddlar's Tunnel. The only other opilionid taken was a single specimen of *Oligolophus tridens* (C. L. Koch) (Phalangiidae) in Cheverie Cave (Hants County).

Peddlar's Tunnel is an abandoned mine adit, part of the workings of Tennycape Manganese Mine dating from the end of the 19th Century (Weeks, 1948). It is situated at an altitude of approximately 50 m near Route 215, east of Walton on the Minas Basin coast of Nova Scotia. The tunnel is 50 m in length, approximately 2 m x 1.25 m in cross section, driven due north. Due to a slight bend at 24 m, the entrance is not visible looking back from the end of the tunnel, but reflected light is still visible. The entrance is almost blocked by an accumulation of debris, leaf mould and porcupine scat, creating a dam. Except during times of extreme drought, the tunnel is flooded with up to 1 m

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of water. Due to this water and the constricted entrance, relative humidity is close to 100%.

Overwintering *Leiobunum elegans* were first noticed in the adit in late 1994, and were observed in three consecutive winters: 1994/1995, 1995/1996 and 1996/1997. The animals were located between the bend and the inner end of the tunnel. A count made in January 1997 found 864 individuals: 27 (3%) occuring singly, 188 (22%) in small groups of 2-52, and 649 (75%) in aggregations of 73-156. During visits made in 1996/1997 aggregations were observed to have been formed by October 1996. By April 1997 they were breaking up and the animals had started dispersing out of the tunnel: there were fewer animals in total, and several individuals were also seen just inside the tunnel entrance.

Collections made from the aggregations in Peddlar's Tunnel October 1996 and April 1997 were all adult males and females. By contrast, all specimens collected from other sites of isolated individuals and small groups were sub-adults.

These records of overwintering *Leiobunum elegans* show it to be widely distributed in the geographical region investigated. It probably occurs in winter in most of the caves and mines in Nova Scotia, typically moving into overwintering sites during October, and apparently dispersing in April-May.

Aggregation formation is a well established phenomenon in opilionids. It is apparently a behavioural adaptation for coping with environmental extremes. It is obvious that the animals use caves in winter to avoid harsh seasonal conditions, but the reason that populations at some sites form aggregations is unknown. The results show that aggression is not compulsory because aggregates have been observed at only one site in small numbers compared to those found in *Helima paessleri* communities. Holmberg *et al.* suggested that the combined effects of many opilionids' scent glands may be more effective at repelling predators, but we believe a more likely explanation is that it is a behavioural adaptation for the maintainance of water balance. Ambient relative humidity is a critical factor for most cave organisms, and obligate cavernicoles ("troglobites") appear to be adapted to an environment where the relative humidity is always at or near 100% (see, for example, Howarth, 1979). However, most terrestrial arthropods are physiologically adapted to desiccating environments, and thus they may have difficulties coping with saturated atmospheres (Bursell, 1974). It is reasonable to expect that animals that spend only a part of their life in caves have evolved strategies to overcome this problem. There is some evidence that overwintering aggregations only form in underground sites where the relative humidity remains at, or near, 100%: Holmberg *et al.* (1984) mention that their sites all had high humidity and supplies of free water, and this is also the case in Peddlar's Tunnel. The densely intertwined legs may reduce air movement and help prevent precipitation of liquid water on the bodies of the animals.

A major pattern of life history in North American *Leiobunum* species is to overwinter as eggs. However some species winter-over as sub-adults, maturing and mating in the spring (Edgar, 1971 p. 10). In *Nelima paessleri*, it is only the mature adults that overwinter (Holmberg *et al.*, 1984). Based on the extant records it appears that *Leiobunum elegans* in Nova Scotia overwinters both as adults and sub-adults, only the adults forming aggregations. More records are required in order to confirm this observation.

The following specialists very kindly gave of their time to identify the collections: Drs. R. Holmberg (Athabasca University) and L. Brown (Gardner-Webb University) determined material from Peddlar's Tunnel; Dr. C. Dondale (Canada) determined the (sub-adult) specimens from all other sites. C. Ewing (Nova Scotia Museum of Natural

History) determined the specimen of *Oligolophus*. Part of the cost of field work was defrayed by a Nova Scotia Museum Research Grant to one of the authors (M.M.).

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OBITUARIES

D.H. Davies, B.Sc., Ph.D., a biographical sketch

Donald H. Davies was born in Ottawa in 1938, an only son. After graduating with an honours B.Sc. from Carleton University, he went to England where he completed his Ph.D. in experimental physical chemistry at the University of Bristol. Dr. D.H. Davies joined the Chemistry Department at Dalhousie in 1965. He moved to the Chemistry Department at Saint Mary's University four years later, and he remained there until he retired in 1994. Dr. Davies served on a number of sports administering bodies since the early 70's: he was president of the Shooting Federation of N.S. and past president of Sport Nova Scotia. As director of the Shooting Federation of Canada, he arranged the shooting events for the Pan American Wheel Chair Games held in Halifax. He served as Executive Vice-President of the Sports Federation of Canada. Don took a keen interest in equestrian activities and rode his own horse, Krios, for many years. He died suddenly on May 29, 2000. He is survived by his wife, Sherill, son, Cedric, and daughter, Eleanor Allison.

Don had a very sharp mind and an infectious twinkle in his eye. This occurred especially when, in an argument or debate, he bettered his opponent, which he usually did. He set high standards for students, and did his best to encourage them to rise to the challenge.

Don Davies had been a major contributor to chemical affairs in Halifax for some thirty years. This began with his working for the annual national meeting of the Chemical Institute of Canada (C.I.C.) with some 1200 chemists in Halifax in 1971. He was elected a Fellow of the C.I.C. in 1978 and was a member of the Executive of the Atlantic Section for many years.

He was a founding member in 1978 of Nova Chem Ltd., later renamed Chitogenics Ltd. It has become North America's leading developer of carboxymethyl derivatives of polyglucosamine. These compounds readily form films, sponges, foams, beads, gels and viscoelastic solutions. Many practical applications are derived therefrom. More information can be found from the company's web side, www.chitogenics.ns.ca.

Don Davies joined the Nova Scotian Institute of Science in the 1970's, and he was a member of the NSIS Council from 1980 until 2000. He was the NSIS Treasurer from 1988 until he died. Under his auspices the total liabilities and financial net worth of the NSIS over the past nine years has increased by 55%! The growing finances of our Institute were achieved primarily by our dedicated and knowledgeable Treasurer, Donald H. Davies, even though our membership has declined over that period.

Don Davies was a strong source of common sense. For example, the By-Laws of the Nova Scotian Institute of Science had not been revised since 1981. Don Davies urged the Council to have the By-Laws revised, and he made several specific, sensible suggestions. New NSIS By-Laws were accepted unanimously in our May 1, 2000 Annual General Meeting.

All of us who know Don Davies, including members of the past as well as the present NSIS Councils were shocked by his sudden death and saddened by our loss of him. Let us remember what he did for us as well as his family and other parts of the community.

H.S. Heaps, D. Eng., L.L.D.; a biographical sketch

Dr. Stanley Heaps, distinguished computing scientist and applied mathematician, died peacefully at home in Halifax on 12 June 1999, after a short illness. Members of the Nova Scotian Institute of Science will remember him as one of our Institute's most loyal and active members for many years. Stan joined the Institute in 1951. From 1954 to 1967 he served on the Council, Recording Secretary 1955-1960 and Editor of the Proceedings of NSIS from 1957 to 1964. On leaving Halifax for the University of Alberta in 1967, he was made an Honorary Life Member of the NSIS. On Stan Heaps' return to Halifax in 1979, he again became an active member of the Institute, serving as NSIS Vice President 1996-97, President 1997-98 and Past President 1998-99. We shall miss him very much.

Stanley Heaps was born in Stockport, England in 1926. He obtained a B.Sc. in Applied Mathematics at the University of Manchester in 1947. He then moved to Canada where he was a Lecturer in Mathematics at Dalhousie University for two years. (I took a full year course from Stan each year and found him a very good teacher). He spent the next two years as a Teaching Fellow at the University of Toronto, where he obtained his M.A. Mathematics. In the 1949 and 1950 summers he worked at the National Research Council Laboratory in Ottawa on chemical physics with the famous Gerhard Herzberg, Nobel Laureate. H.S. Heaps' first published paper was coauthored with Dr. Herzberg.

Stanley Heaps returned to Halifax in 1951 as a full-time faculty member in the Nova Scotia Technical College (later TUNS and now DalTech). He was responsible for the establishment of the Department of Engineering Mathematics. He stayed at NSTC for fifteen years. In succession he was Assistant Professor, Associate Professor, Professor and Head of the Department of Engineering Mathematics. During this period, 1952-67, Stan was a mathematical consultant at the Naval Research Establishment (now DREA) in Dartmouth.

In 1966-67, as a result of plans to develop a co-operative computing science teaching facility and centre for most of the Nova Scotia universities, Stan was interim Director of the Computer Centre and Professor of Mathematics at Dalhousie. This facility did not materialize, and Stan left for the University of Alberta. Stan and his wife, Doreen (Alley) Heaps, were faculty members of that University for the period 1967-72. Stan was Professor and Assistant Chairman in the Department of Computing Science. There Stan helped establish a graduate program leading to a Ph.D. in Computing Science, and he supervised nine graduate students. He was active in the Edmonton Chapter of CIPS, being President 1971-72.

In 1972 Stan was invited to Sir George Williams University in Montreal. Shortly afterwards it amalgamated with Loyola College to become Concordia University. There Professor Heaps developed the School of Computer Science in the renamed Faculty of Engineering and Computer Science. By the time he left in 1979 that Department had grown to a faculty of 24 and some 60 graduate students.

Stan (with Doreen) returned to Halifax in 1979 to be Professor and Head of the Department of Applied Mathematics at TUNS as a step in the development of a school of computer science. He became the founding Director of TUNS School of Computer Science, 1982-87. This School grew rapidly and is now the Faculty of Computer Science at DalTech. In the year following his retirement as Director, Dr. H. Stanley Heaps served as Acting Vice President of Research at TUNS, 1987-88.

As he had earlier supported NSIS, on his return to Halifax Stan supported all community activities related to computing science, both technically and socially. These activities included the Canadian Information Processing Society, Bluenose Chapter (Chairman of a Scholarship Committee - the computing science scholarship now carries his name), the Macintosh Users' Group of Nova Scotia or MUGNS (Secretary), and the Chebucto Community Net. Stan developed web pages and maintained accessible lists such as a list of scientific equipment for the Institute.

During his career H.S. Heaps published 67 research papers in a variety of areas including molecular physics, acoustics, applied mathematics, computer science, electrical engineering, mechanical engineering and information science. He also published two books. A scientist from another field can obtain some sense of the importance, several years later, of a published paper by looking up the number of citations of the paper as listed in Science Citation Index. By this criterion, H.S. Heaps published the following well cited articles:

H.S. Heaps and G. Herzberg, Z. Phys. **133**, 48 (1953). Intensity distribution in the rotation-vibration spectrum of the OH molecule.

H.S. Heaps, J. Acoust. Soc. Am. **34**, 355 (1962). Waveform of finite amplitude derived from equations of hydrodynamics.

H.S. Heaps and R.V. Wells, Can. J. Chem. Engin. **43**, 319 (1995). The effect of noise on process optimization.

H.S. Heaps and L.H. Thiel, Inform. Storage and Retrieval **6**, 137 (1970). Optimum procedures for economic information and retrieval.

L.H. Thiel and H.S. Heaps, Inform. Stor. Retriev. **8**, 1 (1972). Program design for retrospective searches on large data bases.

E.J. Schuegraf and H.S. Heaps, Can. J. Operational Res. Inform. Processing **10**, 47 (1973). Storage analysis of a compression coding for document data bases.

E.J. Schuegraf and H.S. Heaps, Inform. Stor. Retriev. **11**, 309 (1974). A comparison of algorithms for data base compression.

Also popular is the second book published by H.S. Heaps, *Information Retrieval: Computational and Theoretical Aspects*, (Academic Press, New York, 1978). The book is intended for undergraduate computer science students, librarians and information officers.

H. Stanley Heaps received a number of important academic honours. He was a Charter ISP member and an Honorary Life Member of the Canadian Information Processing Society, an Honorary Life Member of the NSIS and a Fellow of the Acoustical Society of America, and he had the distinction of receiving two honorary degrees. In 1987 St. Francis Xavier University conferred upon him the degree of Doctor of Laws, Honoris Causa. In 1993 the Technical University of Nova Scotia conferred on him the degree of Doctor of Engineering, Honoris Causa. An endowment fund in his name has been established by St. Francis Xavier University.

I believe that all NSIS members who knew Stan well appreciated him as a fine person and someone who worked hard and successfully for the Institute. He was witty, clever and determined to get things done. He was a very good teacher of computing science and of applied mathematics. He was an excellent computer programmer and a first rate researcher. Let us remember him with great respect and affection.

Donald D. Betts, NSIS President, 1999-2000.

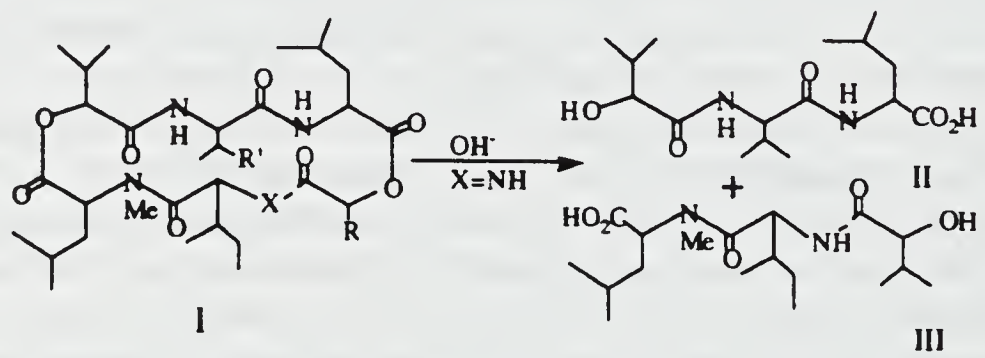
Several friends and colleagues helped me to write the above sketch. Mrs. Doreen Heaps, Stan's sailing companion and loving wife for many years, was particularly helpful and I thank her very much.

D.W. Russell

Dr. Douglas William Russell (Treasurer, 1967-1970) who died in June 1999 was born on 19th September 1926 at London, England. He was educated at Colchester Grammar School in Essex, and after working as an apprentice pharmacist, went up to read pharmacy and pharmcognosy at the Pharmacy School at Chelsea Polytechnic where he graduated with first class honours in 1949. Following National Service in the Royal Air Force, he pursued a Ph.D. degree with Mathieson in the Department of Pharmacy, London University. He then took a temporary post with Elliot in the Medical Research Council's laboratories in Mill Hill and there he was introduced to the difficulties and attractions of α-amino acid and peptide chemistry.

In 1958 he applied for and was awarded a facial eczema research fellowship tenable in New Zealand and was fortunate to be exposed to the experimental skills and rigor of R.L.M. Synge. Facial eczema is a condition of young ruminants, prevalent in the North Island of New Zealand that is responsible for major losses of production of high quality edible protein. The condition occurs mainly in the fall and at the time of Russell's appointment was thought to be due to changes in the nutritional quality of herbage especially of perennial rye-grass (*Lolium perenne*). However, the painstaking and brilliant work of E.P. White had shown that it was possible to isolate from pastures where the disease occurred compounds that were not normally found in vascular plants, but were related to known fungal metabolites. These materials had little ovine toxicity but were a reliable indication of herbage, that when consumed led to facial eczema. It was therefore important to investigate these materials and Russell undertook this work.

He was able to isolate the major component of the mixture, sporidesmolide I (I, X=NH, R=C_3H_7, R'=Me), by fractional crystallization and to determine its structure by showing it to be readily converted by mild alkaline hydrolysis into two sporidesmolic acids (II & III), easily separable, crystalline and accounting for all the carbon and nitrogen atoms in sporidesmolide I. His proposal was confirmed independently by mass spectroscopy (Macdonald et al., 1964) and by synthesis (Shemyakin et al., 1963) and thus became the first depsipeptide (a term coined by Shemyakin to describe compounds built of α-hydroxy- and α-amino acids linked together by amide and ester bonds) whose structure was rigorously proven.



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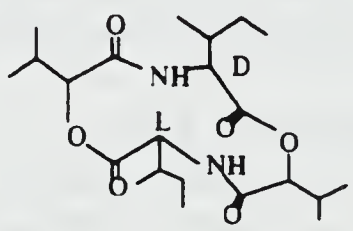
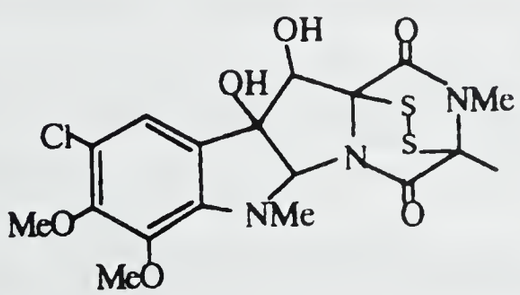


IV

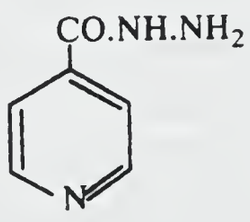
This result had novel biological implications. Russell had shown that the depsipeptide material was found only in cultures of *Pithomyces chartarum* that sporulated. This observation was enhanced by the demonstration (Bertaud et al., 1965) that electron diffraction patterns could be obtained by irradiating spores (caught in spore traps) with electron beams. These diffraction patterns were identical to those obtained by irradiation of sporidesmolides. In addition, single spores introduced into the source of a mass spectrometer (Macdonald et al., 1964) gave mass spectra identical to those of the sporidesmolides. Thus the long-standing question of whether "secondary metabolites" were a mere artifact of the culture of microörganisms, or whether they were an intrinsic manifestation of their growth and reproduction was settled.

A second and perhaps more important influence of this work was that the demonstrated, crystalline spore coat of depsipeptides contributed a massive concentration barrier between the spore and encroaching pathogens. Clearly the concentration at which these depsipeptide metabolites inhibit growth *in vitro* is irrelevant to their role in nature. This phenomenon is only now, 30 years later, becoming appreciated in the context of the growing interest of using biocontrol mechanisms (Hjeljord and Tronsmo, 1998) in horticulture.

In 1962, Russell was offered a post at the Twyford Laboratories in London where he used his proximity to The Commonwealth Mycological Institute and M.B. Ellis to pursue the possible taxonomic implications of the New Zealand discoveries. Ellis (1960) had revised the taxonomy of some of the Dictyosporus group of the Hyphomycetes and had several viable specimens of organisms he had placed in the genus *Pithomyces*. Russell examined all of these and found that all had crystalline spore coats that were depsipeptides. Further, the depsipeptides of Ellis's assigned species differed in each species thus substantiating their classifications. These bald sentences conceal a great deal of chemistry, for each species produced a mixture of depsipeptides, difficult to separate and characterize. This work was in full swing when Russell decided to leave London and accept an associate professorship in the Biochemistry Department at Dalhousie University. He made full use of the laudable custom in the Department of a year free of teaching responsibilities and produced six papers that year, including a review of depsipeptide chemistry that was and is a landmark in the field. During the following years, indeed until 1990, he collaborated with colleagues and trained several summer and post-graduate students. The results of this work were the determination of the structures of sporidesmolide II, sporidesmolide IV, (I, X=NH, R=C_4H_9, R'=Me), sporidesmolide V, pimaydolide (I, X=O, R=C_4H_9, R'=Me) and angolide (IV). These taxonomic studies had unexpected practical value in the late 1980's when Russell and his colleagues showed that the populations of *Pithomyces chartarum* in the Americas differed from those in Australia, New Zealand and South Africa because they always produced sporidesmolides but did not usually produce toxic sporidesmins (e.g. V).



V



VI

This was also also the first chemo-taxonomic study based on a solid biochemical foundation.

In these years he also contributed to our knowledge of the anti-tubercular drug isoniazid (VI). He developed a simple method for measuring the concentration of this drug in urine, and proved its reliability under difficult conditions in a remote region of Ethiopia. He showed that the act of acetylation and subsequent excretion of isoniazid was very different in individuals of different ethnicity. Knowledge of the pharmacology of isoniazid is of increasing importance as the scourge of tuberculosis, once again, is increasing (Rouhi, 1999).

After a few years at Dalhousie, formal teaching in lectures, tutorials and laboratories gradually assumed a larger role in Russell's life at the University. At one time or another, he participated in teaching biochemistry to students in all of the health professional streams - medicine, dentistry and pharmacy, as well as undergraduate students in the Faculty of Science. His outlook was, as in his research, rigorous: to keep the discussion simple if possible, but never to fudge the facts. He was a chemist first, a biologist second; to him thermodynamics was fundamental and he refused resolutely to dilute his approach. In comprehensive oral examinations of graduate and senior undergraduate students he was fond of asking "How can you establish the structure of a newly-discovered substance ?" The answer he wanted was "Show that its properties match those of a compound that has been synthesized by an unambiguous route". To him, the current phrase "isolating a gene" glosses over the undeniable fact that the gene in question is never characterized chemically, and is usually inserted into a convenient vector.

Russell's teaching career took an unusual turn in the late 1970's, when he decided that he wanted to do something to improve the teaching of science in high schools. He did this in a characteristically thorough way by enrolling in the Department of Education and obtaining a Bachelor of Education degree and a Teaching Certificate. Subsequently he served for five years as the co-ordinator for secondary science in the Dalhousie Department of Education, and science teachers throughout the Province have benefitted as a result of his efforts and enthusiasm. Russell was also alive to the changes in medical education now sweeping Medical and Pharmacy schools. He adapted willingly and skilfully to the idea that he must refrain from providing answers, but instead must facilitate the student's struggle to understand illustrative cases (many of which he helped to develop). Russell continued to work to improve his teaching until he died, leaving useful notes describing his ideas for modifications to be made in the coming year.

We are all the poorer that he will not be with us to encourage us with his enthusiasm, his friendship and his knowledge; we extend our deepest sympathy to his family.

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President's Reports

1997-1998 Dr. S.H. Heaps

I am pleased to report that 1997-98 has been a good year for the Nova Scotian Institute of Science. Meetings held on the first Monday of each month from October to May have included four meetings with a single speaker and four panel discussions involving several speakers. Attendance at meetings has been good. On two occasions the auditorium at the Nova Scotia Museum of Natural History was filled to capacity and there were people sitting in the aisles. This suggests that we are choosing the right topics for discussion.

It also leads me to conclude that the Institute is continuing to serve an important role and that it should continue to focus on topics of interest and importance to both active scientists, administrators of scientific organizations, those involved in government, as well as the general public. There is perhaps no other organization in Nova Scotia that is so well prepared to fill this role.

From time to time the Institute receives requests to comment on various proposals from government groups. We have contributed some feedback during the past year and I believe this is an activity to which we might devote greater attention in future years. Collectively the members of the Institute possess a great deal of knowledge and experience relating to science, and they do not have ties to particular organizations or special interest groups.

This year the Council of the Institute decided to take an active part in the Science Fairs that are directed at high school students. The Institute donated an award and will soon review the results with a view to deciding whether to continue the award in future years. I wish to thank our Secretary, Dr. Sherry Niven, for handling the details of this activity.

The Proceedings of the Institute are being published on a regular basis of one issue each year. I wish to thank our Editor, Dr. R.P. Gupta, who is responsible for all matters relating to the Proceedings.

You will be pleased to hear that the Institute is in good shape financially. This year the Council of the Institute agreed to implement a plan by which the Institute funds will be invested in a regular manner so as to receive the best interest rates compatible with fully guaranteed principal.

During the past year the Council of the Institute has included three observers. They are Debra Burleson and Alex Wilson of the Nova Scotia Museum of Natural History and Nan MacDonald of the Discovery Centre. These three have been valuable members of council and we appreciate their interest and support.

The regular monthly meetings of the Institute are open to the public. At most meetings there are many in the audience who are not members of the Institute. I believe it is important to increase membership of the Institute, not primarily to collect more membership fees, but in order that we can claim to represent a larger cross-section of the concerned public.

I believe we should give more consideration to means of publicizing the aims and activities of the Institute. I suspect that most local scientists are aware of the existence of the Institute but may not be aware of how it can benefit them by presenting their concerns to the public, industry, administrators, and government. It can also present the concerns of these groups to the scientists. I have the impression that our attempts to publicize the activities of the Institute have been worthwhile and have led to an increased attendance at meetings. However, we still have a long way to go.

It has been a pleasure and an honour to be President of the Institute during 1997-98. I am sure that all members of the Institute would like me to express thanks to those who have served as members of the Council during the past year.

Respectfully submitted,
Dr. H.S. Heaps
1997-98 NSIS President
May, 1998

1998-1999 Dr. Skerry E.H. Niven

My goal this year, as President of the Nova Scotian Institute of Science, was to highlight the scientific excellence of our province as well as the importance of scientific research to Nova Scotians. The talks and discussions for the monthly lecture series, listed below, were chosen with this goal in mind (see Proceedings).

Thanks to our excellent speakers and panelists, the lecture series was very successful. Large audiences were treated to interesting presentations and lively discussions. This year's lecture series highlighted the important role that the Institute plays in providing a regular forum for good scientific discussion. On behalf of the Council, I thank the series participants for the time and effort that they gave to the Institute to make the lecture series such a success. We also thank the Nova Scotia Museum of Natural History for the use of the auditorium and the South room for our meetings. Special thanks to Alex Wilson for his support and assistance throughout the year. Thanks also to Dr. Mary Anne White for suggesting the NSERC President, Dr. Brzustowski, as a speaker this year. Robert Roy, Public Relations Officer for NSERC, worked diligently with me to make the visit a reality. Thank you!

For National Science and Technology Week (October 1998), the NSIS prepared a poster celebrating the history of scientific excellence in Nova Scotia. The poster featured six scientists and inventors from Nova Scotia who are recognized throughout the world to have influenced the direction and development of their fields of research:

- Dr. Oswald Avery, the father of modern DNA-based genetics;
- Mr. Frederick G. Creed, inventor of the first data communications technology;
- Dr. Abraham Gesner, the inventor of kerosene;
- Dr. Charles Huggins, renowned oncologist and Nova Scotia's only Nobel Prize winner;
- Dr. Simon Newcombe, astronomer and one of the most influential scientists of the 19th century;
- Dr. Reginald Ruggles Gates, who furthered the development of cytological genetics and pioneered the use of blood typing in Physical Anthropology.

These scientists were also featured at the monthly lecture series.

Members of the scientific community have come to realize that public advocacy is necessary to ensure continued conduct of world class science in Canada. Consequently, the Council has begun to explore the role that the NSIS can play in science advocacy in Nova Scotia. We will work with other groups promoting science in Nova Scotia to formulate a strategic plan for increasing science advocacy and lobbying on behalf of the scientific community in Nova Scotia. Next year we will complete work started this year to update the NSIS By-Laws and to write a mission statement and a strategic plan for the Institute. These will be submitted for approval by the membership at the 2000 AGM. The Institute can act a credible, independent voice for scientists throughout Nova Scotia; however, we need to represent a larger portion of the scientific

community if we are to be effective in science advocacy and lobbying. The strategic plan will include plans to expand the membership.

The Council focussed its activities this year around the objective of "representing science and scientists in Nova Scotia and presenting Nova Scotia science to the public of the province." I joined the Board of the Atlantic Science Links Association to develop partnerships in science outreach with other science promotion groups in the province. Also, in addition to taking part in the National Science and Technology Week,

- The Institute awarded a prize at the Halifax Regional Science Fair for the best innovative multidisciplinary project. The money for the award ($50) was raised through the sales of the Year of the Oceans calendar kindly donated by Fisheries and Oceans Canada;
- The Council donated $200 (remaining from funds allocated for donation last year) to a workshop in November involving scientists and administrators from universities, government labs, and the private sector throughout the province to develop an action plan to increase the retention of women in science, engineering, and math; and
- We hosted another very successful *Science - A Family Affair* workshop at Dalhousie on May 1st. A dozen elementary students and their families enjoyed a morning of fun, hands-on science activities under the guidance of Mr. Surjit Verma. Thanks to Mr. Verma, Dr. Stephen Payne, and Mr. Peter Shacklock for organizing and running the workshop.

As a result of increasing requests from other science organizations for financial support of their projects, the Council has started to develop a policy on donations. This policy will be part of the Institute's strategic plan and a responsible financial plan in which expenditures will be focussed on the Proceedings and other primary NSIS activities such as the monthly lecture series.

Publication of the Proceedings demands most of the Institute's available finances, even with the generous assistance provided by the Nova Scotia Museum of Natural History. To ensure regular publication of the proceedings while allowing the Institute to increase other activities related to its mandate, the Council is proposing an increase in annual membership to $20. Tax-deductible donations can also be made toward specific Institute activities.

Dr. R.P. Gupta resigned as Editor of the Proceedings this year as he was unable to carry out his duties while away on sabbatical. Dr. Stephen Payne has stepped in as Editor - thank you, Stephen! This year's Proceedings will be published this summer. Thank you to the Nova Scotia Museum of Natural History for its continued financial support of the Proceedings.

Under the leadership of Dr. Stan Heaps, the Council has been working to complete the Institute's collection at the Nova Scotia Public Archives. Records have not been archived for the past few decades.

To allow advertisement on the NSIS web page of the database of fungal isolates and cultures in Canada, the Council has completed the agreement with NRC, started in 1991, which grants a special licence to the Institute to distribute the database. The Council thanks Dr. Alan Taylor for his continued work with the database, voluntarily maintaining and updating it for the benefit of the Institute. Thanks also to Dr. Stan Heaps for maintaining the website.

An external accountant audited the Institute's financial records this year since an internal audit has not been carried out for several years. Annual appointment of an auditor will resume this year.

I have very much enjoyed serving as the President of the NSIS this past year and

working with the Councillors for the science community in Nova Scotia. Together we have worked toward strengthening the Institute's role in representing science and scientists in Nova Scotia. Many thanks to you all!

1999-2000 Dr. D.D. Betts, FRSC

The Nova Scotian Institute of Science, NSIS, was founded in 1862. It has continued vigorously until now, and it will continue for years to come. Once a month from October to May, this society provides free public lectures or panel discussions on various aspects of science and technology. On average once a year NSIS publishes its Proceeding, a scientific research journal, distributed to libraries worldwide. NSIS maintains a valuable science library within the Dalhousie Killam Library. NSIS provides financial and personal support to high school science fairs. Overall, our institute does its best to acquaint the general public in Nova Scotia with up-to-date science and its benefits to society.

In our General Meetings this year we have held five free public lectures in the Nova Scotia Museum with an average audience of fifty. Members of the NSIS Council knew that a larger general audience attends our panel discussions. Therefore we decided that the 1 November 1999 and 6 March 2000 public panel discussions would be held in the Guptill Theatre in the Dunn Building at Dalhousie University. We have been very pleased that on each occasion there was an audience of about 150. Furthermore, reporters from the Chronicle Herald and Daily News took notes and representatives from CJCH, CKDU and CBC radio stations taped the discussion for broadcasting locally and nationally. Details of our public lectures and panel discussions are given in the list of the Proceedings of the Institute.

Our finances are in excellent condition with a surplus of over fifty thousand dollars largely due to the work of our Treasurer, Dr. Donald Davies. We have thus readily supported the IUPAC Conference on Chemical Thermodynamics organized by Dr. Mary Anne White here in Halifax this summer. The 1981 By-Laws of the Nova Scotian Institute of Science have been carefully revised this year by a committee chaired by Dr. Sherry Niven, our Past President. Distribution of notices of our monthly meetings for the public has been very well handled by our new Publicity Officer, Peter Shacklock. Indeed the whole Council has worked cooperatively and vigorously this year, and in the recent past (I joined only in 1996).

I am sad to report that Dr. H. Stanley Heaps, the NSIS President 1997-98, died last June after a short illness. He was one of our Institute's most loyal and active members for many years starting half a century ago. We miss him very much. His obituary will appear in the next issue of the NSIS Proceedings, soon to appear.

Now a few words about our Proceedings. Between 1975 and 1995, there was a Volume each year with three or four parts and several hundred pages. Over the past 5 years, under 3 successive editors, only three issues have been published with a total of about 300 pages. I do not blame editors, authors or members of the Institute; I know we are all very busy and we do what we can. I do see light down the tunnel. Dr. Payne, the Proceedings Editor will send Volume 41 Part 4 to Dalhousie Graphics and thence to the printers. We should receie it in a few months. Secondly, Dr. Willison is Guest Editor of a special issue (Volume 42 Part 1) focused on deep sea corals and the August 2000 international congress on that subject. We are also concerned about our membership. Twelve years ago it was about 225, but recently it has declined to about two-thirds of that number. However, we are establishing a Membership Committee for the coming year and we expect the membership to climb again. Two longstanding

members of NSIS, Drs. Michael Falk and David Jamieson, saved us this past month from having to pay for an accountant. With Dr. Don Davies they carefully went over NSIS financial accounts and found everything in good shape. On behalf of the membership, I thank them very much for this work. Indeed I thank everyone who has played a role in NSIS this year. I have so enjoyed my role this year as NSIS President that I could even be persuaded to continue for a second year.

PROCEEDINGS

Proceedings of the Institute (1998-1999)

5 October 1998
Dr. Sara Iverson, *Department of Biology, Dalhousie University,* **Fat: An Ecological Tool.** Although "fat" may at first glance seem like a very simple, uninteresting and even negative thing, in many animal species it may be the single most important component in their life cycle - and it may even provide us with clues as to how some animals make their living in the wild. From providing insights into how fasting grey seal females transfer 23,000 calories in milk per day to their pups, to understanding how dolphins travel so efficiently, to detecting the at-sea foraging behaviour of Antarctic fur seals, fat can be a powerful study tool in understanding animal ecology.

2 November 1999
Public Funding of Research: Are we investing wisely in the future of our country? Panelists: ***Dr. Bob Boyd*** *(Acting Director-General of Institute for Marine Biosciences, NRC);* ***Dr. Colin Dodds*** *(VP Academic and Research, St. Mary's University);* ***Dr. Ross McCurdy*** *(CEO, InNOVAcorp);* ***Dr. Michael Steinitz*** *(Department of Physics, St. Francis Xavier University);* Moderator: ***Dr. Dennis Stairs*** *(Dalhousie Political Science; Chair of the Dalhousie Task Force on Research Policy and Administration)*

7 December 1998
Bob Grantham, *Nova Scotia Museum of Natural History,* **Dinosaurs in Nova Scotia. What happened at the Triassic/Jurassic Boundary?** Nova Scotia is world famous for a major extinction event that occurred at the Triassic/Jurassic boundary 200 million years ago. Where were we? What was living then? What dinosaurs were around? How important are our dinosaur-age creatures? What are the results of a search for the cause of this extinction-level event?

4 January 1999
New Strategies in Fisheries Management. Panelists: ***Dr. Jeff Hutchings*** *(Department of Biology, Dalhousie University);* ***Mr. Neil Bellefontaine*** *(Regional Director General, Maritimes Region, Department of Fisheries and Oceans);* ***Mr. Brian Giroux*** *(Southwest Nova Mobile Gear Association);* Moderator: ***Dr. Martin Willison*** *(Biology, Dalhousie University)*

1 February 1999
Dr. Leo Vining, *Department of Biology, Dalhousie University,* **Antibiotic resistance: Can we win the war against superbugs?** The general rule for any antimicrobial agent is "Use it and lose it." Introducing a new antibiotic modifies the environment and inevitably selects for resistant superbugs. What measures can we take to slow the selection process, protect our inventory of useful antibiotics, and counterattack with new ones? Answers to this question emerge from our growing understanding of the role of antibiotics in nature, how they work and how target organisms acquire resistance.

1 March 1999
Dr. Fred Dobson, *Bedford Institute of Oceanography,* **Storm Waves.** The wind-driven waves at the surface of the sea have fascinated us ever since the first person encountered the ocean. Their genesis, progress and dissipation are of great interest and so they have been extensively studied: a great deal is known by practical people (seamen, surfers) and theoreticians (physicists, chemists, biologists) alike. They continue to sink ships, wash away coastlines and kill people, and there is much still to be learned before we can say we predict them well enough. This talk will outline.the state of our knowledge of storm waves, set straight some common misconceptions (e.g. the existence of "rogue waves"), and show them at full fury in the open sea.

5 April 1999
Discussion Leader: ***Dr. David Pink,*** *Department of Physics, St. Francis Xavier University,* **Ethics in Science - Are Scientists Good Citizens?** Ethics in science and technology go well beyond simply "not cheating". For example, do scientists place adequate priority on research questions selected to address matters of social importance? Do scientists consider whether the results of their research (knowledge, products, etc.) will help or harm the environment? Do scientists avoid seeking answers to controversial questions? Do scientists allow their sponsors' interests to affect the direction and the interpretation of their research?

3 May 1999 (Annual General Meeting)
Dr. Tom Brzustowski, *President, NSERC,* **The Knowledge-Based Economy - Realizing the Nova Scotia Advantage**. The arrival of the Knowledge-Based Economy may be a great opportunity for Nova Scotia. The province rightly prides itself on its many universities, on the large proportion of its population that is well educated, and on its high quality of life. These attributes may add up to a unique advantage for the province in the new global KBE. But in what way? I don't think there is a single way, but there might be a single strategy– the strategy of promoting innovation, of creating new goods and services for the global market, of creating new value-added activity in Nova Scotia. Some of the innovations will originate from intellectual property coming out of discoveries in research in the universities. Other innovations may be the result of people spotting market needs and being the first to meet them. Some of them may be developed by existing companies, others by start-ups, others by multinationals attracted to invest in Nova Scotia, and others still by people networking at the community level. But they all require people who are very competent at what they do, people who are very well informed, people who know markets, others who are entrepreneurs, and others still who can manage a new and growing business line or an entirely new enterprise. And they all require the attitude that Nova Scotia is connected to Canada and the world and "All markets can be our market if we create a great product".

Proceedings of the Institute (1999-2000)

4 October: **Nanotechnologies.**
Dr. Manfred Jericho, *Physics Department, Dalhousie University,* "Nanoscale Science with Needle and Cantilever"; ***Dr. Jurgen Kreuzer****, Physics Department, Dalhousie University,* "Digital Holography with Photons and Electrons".

1 November
The Sydney Tarponds: Environment and Health.
Panelists: ***Dr. Judith Guernsey****, Department of Community Health and Epidemiology, Dalhousie;* ***Professor Helen Mersereau****, Department of Engineering, University of College of Cape Breton;* ***Professor Elizabeth May****, Centre of Excellence for Women's Health, Dalhousie University;* ***Dr. Don Elder****, Environmental Engineering, Jacques Whitford Ltd.* Moderator: ***Professor Raymond Cote****, School of Resource and Environmental Studies, Dalhousie University.*

6 December
Dr. Paul Erickson*, Department of Anthropology, St. Mary's University.* **Urban Archaelogy in Halifax: State of the Art**

3 January
Dr. Richard Nowakowski*, Department of Mathematics and Statistics, Dalhousie University,* **Game Theory.**

7 February: **Disease and the Environment**
Dr. Sandy Kapur*, IWK - Grace Health Centre,* "What we breathe is what we wheeze".
Dr. Ken Renton*, Department of Pharmocology, Dalhousie University,* "Sick makes drugs sicker".

6 March: **Genetically Modified Organisms**
Panelists: ***Dr. Sean Hemmingsen****, Gene Expression, NRC Plant Biotechnology Institute, Saskatoon;* ***Dr. Vett Lloyd****, Biology Department, Dalhousie University;* ***Dr. Jerzy Nowak****, N.S. Agricultural College, Truro;* ***Dr. David Patriquin****, Biology Department, Dalhousie University.* Moderator: ***Dr. Les Haley****, Special Climate Change Advisor, Agriculture and Agrifood Canada, Truro.*

3 April: **Wildlife and Conservation Biology**
Dr.Liette Vasseur*, Environmental Studies Program, St. Mary's University;* ***Dr. Tom Herman****, Centre for Wildlife and Conservation Biology, Acadia University.*

1 May
Dr. John Farley, *retired Dalhousie Biology Professor.* **The Life of Another Canadian Hero, Dr. Brock Chisholm.**

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Nova Scotian Institute of Science Balance Sheet as of March 31, 2000

ASSETS			
Bank Account	7,036.14		
Wood Gundy Account	10.38		
Petty Cash	23.32		
TOTAL CASH		7,069.84	
INVESTMENTS		45,555.78	52,625.62
ACCOUNTS RECEIVABLE			2,848.34
TOTAL ASSETS			55,473.96
LIABILITIES AND NET WORTH:			
ACCOUNTS PAYABLE			555.37
DEFERRED REVENUE			0.00
PERMANENT FUND		6,206.41	
SURPLUS AS OF APRIL 1/99		44,688.00	
EXCESS INCOME (EXPENSES)		4,024.18	
NET WORTH			54,918.59
TOTAL LIABILITIES AND NET WORTH			55,473.96
INVESTMENTS			
CIBC Premium T Bill (monthly interest)	13,555.78		
CIBC Mortgage due Apr. 17/2000@4.75%	8,000.00		
CIBC Trust due Apr. 17/2001@4.85%	8,000.00		
CIBC Mortgage due Apr. 17/2002@4.90%	8,000.00		
CIBC Trust due Apr. 17/2003@4.95%	8,000.00	45,555.78	
RECEIVABLES			
Museum	1,000.00		
Interest	1,400.00		
GST Refundable	448.34		
		2,848.34	
PAYABLES			
Carolyn Bird	55.37		
Science Fairs	500.00	555.37	

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